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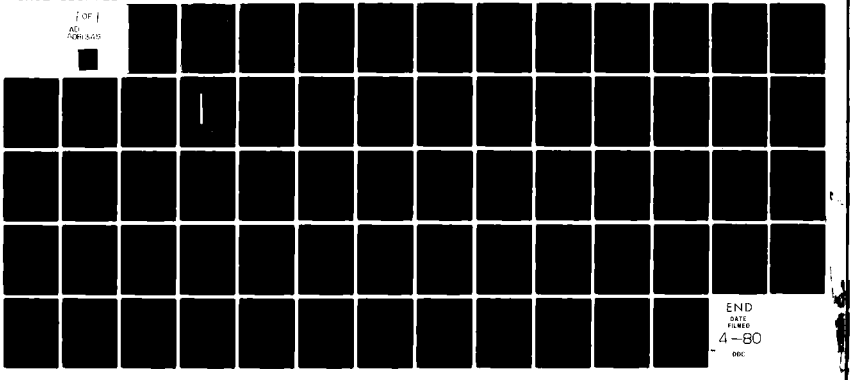

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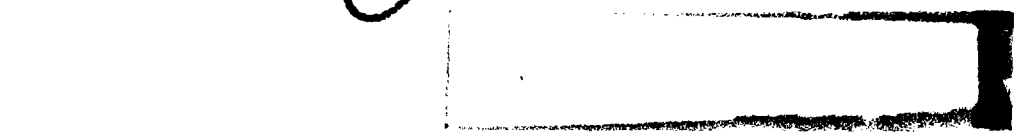

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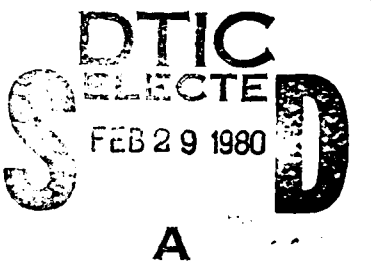

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MODEL TESTS AND ENGINEERING STUDIES OF THE SWATH VII SMALL WATERPLANE AREA TWIN-HULL SHIP.

By

(10) Karl L./Kirkman, B. J./Young
J. W./Kloetzli, P./Majumdar

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The main objective of this effort is to obtain drag data and wake data for the SWATH VII Form, and using this data to obtain estimates of the required propulsive horsepower for the design displacement of 4355 metric tons. A secondary objective was to determine the stern pitch fin settings for minimum drag and, to do this, drag tests were performed for three speeds and a range of fin angles.

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ADMINISTRATIVE INFORMATION

HYDRONAUTICS, Incorporated was authorized (Reference 1) to carry out a program of model tests and related engineering studies of the resistance and propulsion characteristics of a Small Waterplane Area Twin Hull Ship (SWATH) for DTNSRDC, Code 117. This work was sponsored as part of the Task IVA effort by the Advanced Naval Vehicles Concepts Evaluation Project Office (OP 96V). Funding was provided under Program Element Number 63534 N, Project Number SSH15.

INTRODUCTION

The experimental program consisted of resistance (EHP) tests of SWATH VI-A fully appended, resistance (EHP) tests of SWATH VII with and without appendages, a wake survey of SWATH VII fully appended at a speed corresponding to 20 knots full scale, and resistance tests of SWATH VII with various stern fin deflections. The calculations included a design study of alternative wake adapted propellers, and estimates of propulsive performance under certain extraordinary machinery operating conditions.

This report presents the results of the model tests and the calculation of propulsive performance.

BACKGROUND

The main objective of this effort is to obtain drag data and wake data for the SWATH VII Form, and using this data to obtain estimates of the required propulsive horsepower for the design displacement of 4355 metric tons. A secondary objective was to determine the stern pitch fin settings for minimum drag and, to do this, drag tests were performed for three speeds and a range of fin angles.

In addition, in order to obtain direct comparisons between the drag of SWATH VI-A and VII, a drag test of VI-A as received was performed using test procedures consistent with those for SWATH VII.

Description of Ship and Model

A scale model of the SWATH VI-A was furnished to HYDRONAUTICS, Incorporated by DTNSRDC. The scale ratio for this configuration was 22.5:1. The geometric characteristics of the ship and model, designated 7694-1, are given in Table 1. The parameters which most strongly influence drag characteristics are the hull length-to-diameter ratio of 16.0, the strut waterplane area coefficient of 0.85 and the strut maximum thickness of 0.098 meter.

At the conclusion of the comparative drag test of SWATH VI-A, the model was modified to a configuration designated SWATH VII in accordance with instructions from DTNSRDC. The modifications are detailed in the drawings included in Appendix A The model modifications consisted of lengthening the sidehulls, manufacturing new struts, and fitting these parts to the cross-structure at a

Table 1
Geometric Characteristics of Ship and
Model 7694-1

Characteristic	SWATH VI-A Ship	Model 7694-1
Linear Scale Ratio		22.5
Length, Hull, Meter	74.20	3.298
Diameter, Hull, Meter	4.57	0.203
Length, Strut, Meter	52.52	2.334
Spacing, C_L to C_L of hulls, Meter	22.86	1.016
Draft, Meter	8.13	0.361
Trim, Meter	0	0
Displacement, Metric Tons, kgs	2922	249.52
Wetted Surface:		
Sidehulls and Struts, M^2	2534.62	5.007
Bow Pitch Fins, M^2	34.524	0.0682
Stern Pitch Fins, M^2	100.93	0.1994
Prismatic Coefficient, Hull	0.85	0.85
Thickness, Strut, Meter	2.21	0.098
Waterplane Area Coefficient, Strut	0.85	0.85

slightly increased spacing between sidehulls. The characteristics of this configuration, designated Model 7694-2, are given in Table 2. Photographs of the model are given in Figure 1. Of these changes, the parameter mainly responsible for the greatly improved wavemaking characteristics that were measured was the new hull length-to-diameter ratio of 20. The new strut had a slightly reduced maximum thickness of 0.095 meter, but the waterplane area coefficient remained at 0.85.

Table 2
Geometric Characteristics of Ship and
Model 7694-2

Characteristic	SWATH VII Ship	Model 7694-2
Linear Scale Ratio		24.0
Length, Hull, Meter	97.54	4.064
Diameter, Hull, Meter	4.877	0.203
Prismatic Coefficient, Hull	0.88	0.88
Length, Strut, Meter	66.59	2.775
Thickness, Strut, Meter	2.286	0.095
Waterplane Area Coefficient, Strut	0.85	0.85
Spacing, C_L to C_L of Hulls, Meter	27.13	1.130
Draft, Meter	8.67	0.361
Trim, Meter	0	0
Displacement, Bare Hull, Metric Tons, kgs	4355	N.A.
Wetted Surface:		
Sidehulls and Struts, M^2	3568.3	6.195
Rudders, M^2	103.6	0.180
Bow Pitch Fins, M^2	39.28	0.068
Stern Pitch Fins, M^2	114.84	0.199

FIGURE 1 - PHOTOGRAPH OF SWATH VII, MODEL 7694-2

MODEL TEST PROGRAM

This section of the report describes the test equipment and presents the test results expanded to ship form.

Test Apparatus and Procedures

The experiments were conducted in the HYDRONAUTICS Ship Model Basin (HSMB) which is described in detail in Reference 2. The basin is 420 ft in length, 25 ft wide, and 13 ft deep.

Drag (EHP) Tests

By mutual agreement with DTNSRDC, the drag tests were conducted with the model at zero trim to facilitate correlation with the analytic drag predictions. Further, for the VI-A tests the model was free in heave, but for the VII tests the model was fixed in heave to facilitate testing with numerous pitch fin settings.

In both cases, model drag was measured using standard 4-inch variable reluctance force "block gages."

Wake Survey

The wake survey test to determine the longitudinal, radial and tangential velocity components in the propeller plane was made using a pitot-static yaw head rake. The rake was 4 pitot probes fixed at radial positions of 1.5, 2.7, 3.9 and 5.1 inches model scale from the propeller shaft centerline and is fixed to a shaft supported by the stern tube bearings. The rake was placed so that the probe tips lie in a typical propeller plane,

and rotated in angular position.

The outputs from the pitot tubes were measured by pressure transducers which were connected to the rake by flexible tubing. The rake/transducer assembly was precalibrated, and check cals were made on the individual transducers.

The wake survey was conducted at the 8.67 meter draft for SWATH VII at 20 knots with rudder, bow pitch fin and stern pitch fins all set at nominal zero deflection (parallel to the craft lower-hull centerline). The test measurements were made at 15-degrees radial spacings throughout the 360-degree propeller disc.

REDUCTION AND PRESENTATION OF RESULTS

The data obtained from the various tests have been reduced in accordance with accepted practice as described in detail in the following sections. The predictions are presented in appropriate graphical or tabular form to provide the required information about the ship's performance.

Resistance Characteristics

The resistance data were expanded to ship values using the Froude hypothesis: C_R model equals C_R ship, the ITTC correlation coefficients, and a correlation allowance of 0.0005 specified by DTNSRDC. In computing the frictional resistance of the model and ship, the bow and stern pitch fins were treated as separate surfaces, and the rudders for SWATH VII were considered as an extension of the strut for purposes of calculating their specific friction resistance. A breakdown of the ship wetted surface components is given in Table 3 as used for expanding model data.

The predicted ship EHP values are given in Figure 2 for SWATH VI-A Appended in Figure 3 for SWATH VII Bare Hull, and in Figure 4 for SWATH VII Appended. The EHP values are tabulated in Tables 4, 5 and 6.

Actual test data spots reduced to residuary resistance coefficient, C_R, form are given in Appendix B for further analysis by others.

For the tests with varying stern pitch fin angle, the EHP results are given in Figure 5. This figure shows the variation in EHP with fin angle for three speed contours, V_K = 16, 18 and 20 knots.

Table 3
Ship Wetted Surface Components as Used
for Expanding Model Data

Configuration	Item	Wetted Surface M^2	Characteristic Length, M
SWATH VI-A	Lower Hull	1.7187	3.297
(Model 7694-1)	Strut	0.7846	2.334
	Bow Pitch Fin	0.0341	0.117
	Stern Pitch Fin	0.0997	.201
	Total Wetted Surface, $\Sigma \times 2$	5.2742	--
SWATH VII	Lower Hull	2.1619	4.148
Barehull	Strut	.9356	2.776
(Model 7694-2)	Total Wetted Surface, $\Sigma \times 2$	6.1950	--
SWATH VII	Lower Hull	2.1619	4.148
Appended	Strut/Rudder	1.0255	3.019
(Model 7694-2)	Bow Pitch Fin	0.0341	.117
	Stern Pitch Fin	0.0997	.201
	Total Wetted Surface, $\Sigma \times 2$	6.6424	--

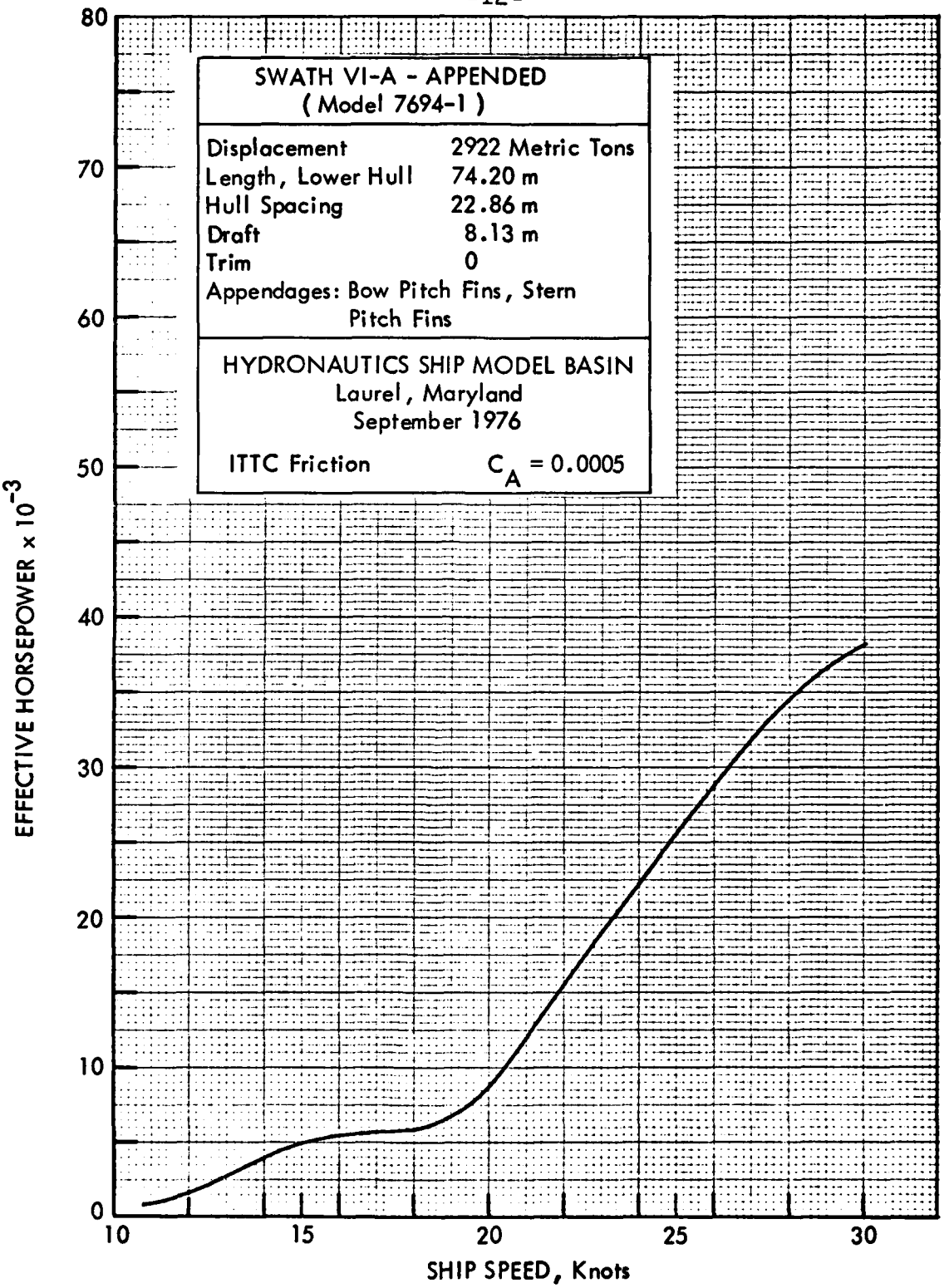


FIGURE 2 - PREDICTED EHP FOR SWATH VI-A - APPENDED

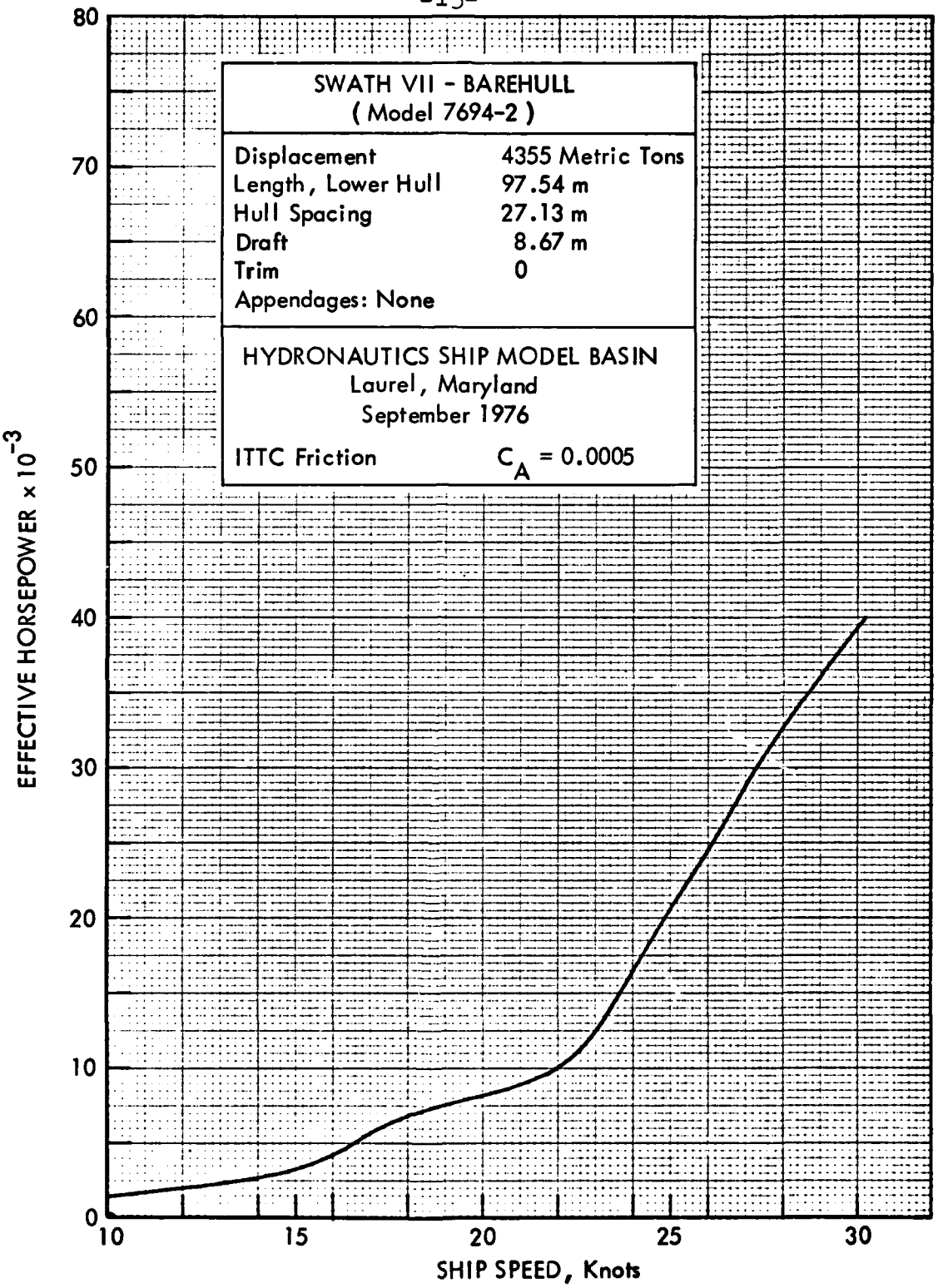


FIGURE 3 - PREDICTED EHP FOR SWATH VII - BARE HULL

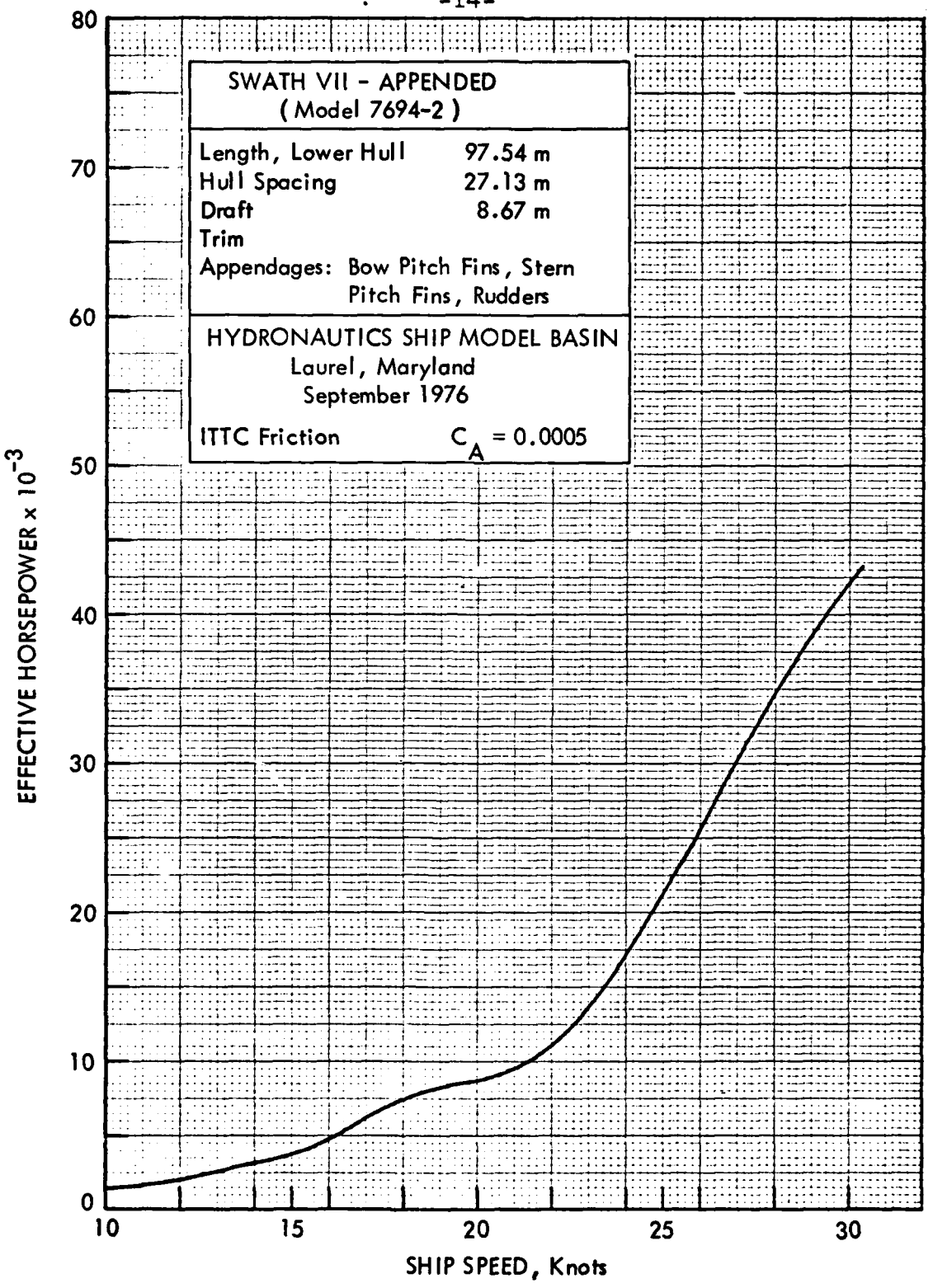


FIGURE 4 - PREDICTED EHP FOR SWATH VII - APPENDED

Table 4
Effective Horsepower for SWATH VI-A
Appended at a Displacement of
2922 Metric Tons

V_K	EHP
12	1,707
14	3,512
16	5,311
18	5,789
20	8,977
22	15,572
24	22,171
26	28,634
28	34,580
29	36,750

Table 5
Effective Horsepower for SWATH VII
Bare Hull at a Displacement of
4355 Metric Tons

V_K	EHP
10	1,097
12	1,803
14	2,643
16	4,277
18	6,854
20	8,140
22	10,287
24	16,695
26	24,611
28	32,624
30	39,833

Table 6
Effective Horsepower for SWATH VII
Appended

V_K Knots	EHP
10	1,169
12	1,988
14	3,104
16	4,631
18	7,518
20	8,615
22	11,107
24	17,342
26	25,832
28	35,163
30	42,850

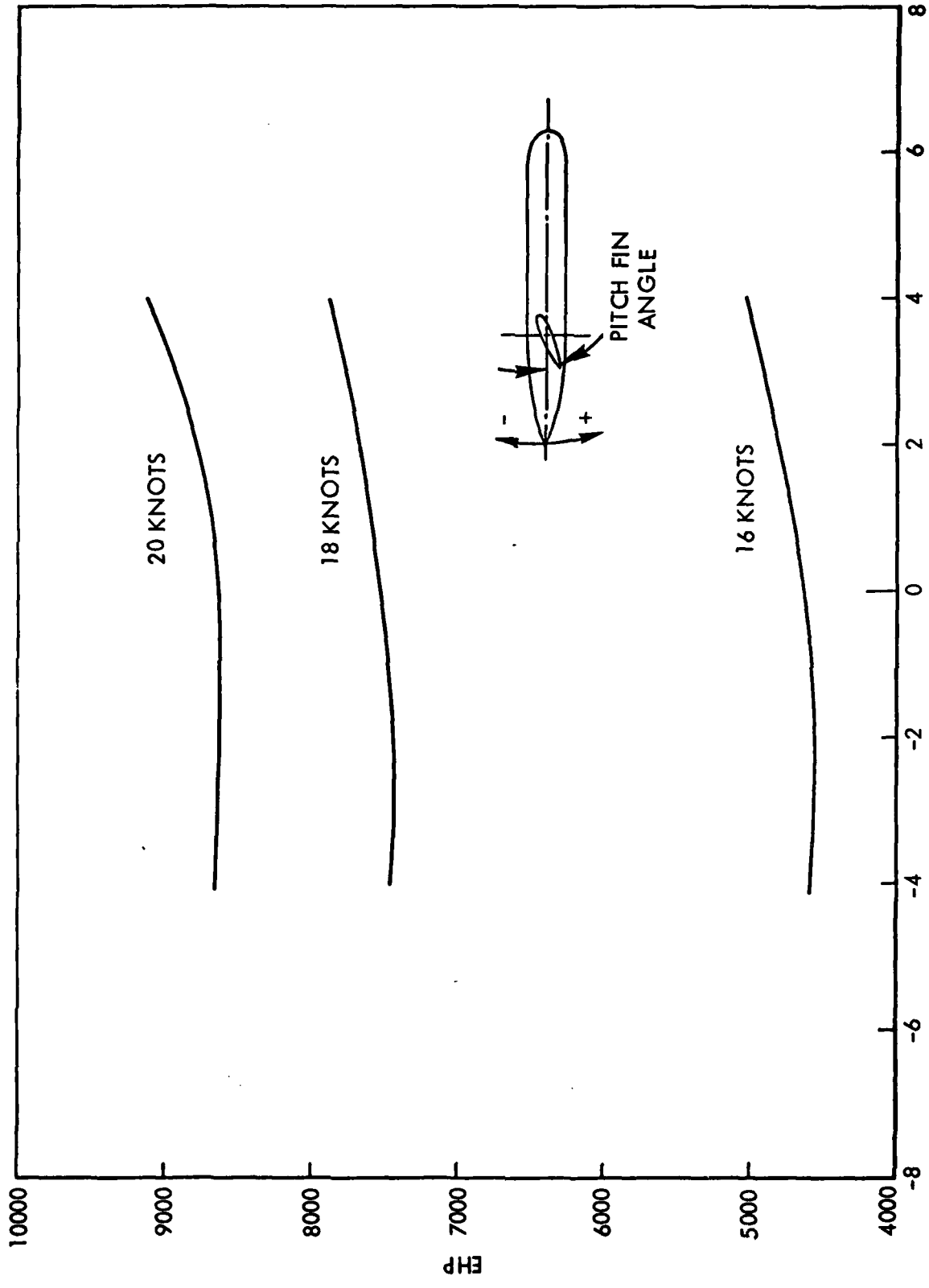


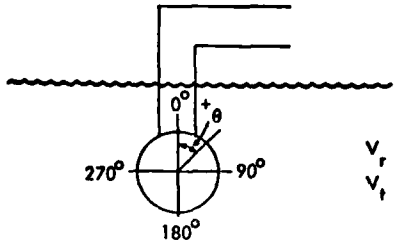
FIGURE 5 - VARIATION OF EHP WITH STERN PITCH FIN ANGLE OF ATTACK FOR FULLY APPENDED SWATH VII

Wake Characteristics

The data derived from the pitot-static yaw head rake measurements in the propeller plane have been reduced to components of longitudinal velocity V_x, radial velocity V_r and tangential velocity V_t. The individual data points, expressed in nondimensional form as ratios to model velocity, are listed in Table 7 for each of the four radial locations. The radial locations are nondimensionalized on lower hull diameter.

The data in Table 7 are plotted to show circumferential variation in Figures 6-9. Figure 6 gives circumferential distribution at $r/r_h = 0.375$, Figure 7 at $r/r_h = 0.675$, Figure 8 at $r/r_h = 0.975$ and Figure 9 for $r/r_h = 1.275$.

A contour map of the longitudinal velocity components is given in Figure 10.



V_r POSITIVE OUTWARD
V_t POSITIVE CLOCKWISE

TABLE 7 - TEST DATA FOR WAKE SURVEY TEST OF SWATH VII - FULLY APPENDED AT 20 KNOTS

$\frac{r}{r_{hull}} = 0.375$				$\frac{r}{r_{hull}} = 0.675$				$\frac{r}{r_{hull}} = 0.975$				$\frac{r}{r_{hull}} = 1.275$			
THETA	V_x	V_r	V_T	THETA	V_x	V_r	V_T	THETA	V_x	V_r	V_T	THETA	V_x	V_r	V_T
0.0	0.7220	-0.1209	0.0641	0.0	0.8368	-0.0761	0.0735	0.0	0.8625	-0.0234	0.0749	0.0	0.8015	0.0163	0.0626
0.0	0.7171	-0.1210	0.0629	0.0	0.8318	-0.0760	0.0729	0.0	0.8558	-0.0272	0.0745	0.0	0.7937	0.0138	0.0600
15.0	0.6428	-0.0573	0.0214	15.0	0.8086	-0.0515	0.0724	15.0	0.9424	-0.0411	0.0847	15.0	0.9827	-0.0196	0.0649
15.0	0.6432	-0.0591	0.0184	15.0	0.8009	-0.0539	0.0712	15.0	0.9277	-0.0408	0.0822	15.0	0.9722	-0.0191	0.0655
30.0	0.5536	0.0279	0.0606	30.0	0.7923	-0.0162	0.0722	30.0	0.9518	-0.0371	0.0782	30.0	1.0084	-0.0260	0.0562
30.0	0.5622	0.0230	0.0576	30.0	0.7880	-0.0132	0.0693	30.0	0.9460	-0.0367	0.0777	30.0	1.0021	-0.0258	0.0561
45.0	0.6388	-0.0026	0.1188	45.0	0.8046	-0.0259	0.0514	45.0	0.9707	-0.0396	0.0712	45.0	1.0027	-0.0210	0.0512
45.0	0.6364	-0.0051	0.1165	45.0	0.7938	-0.0231	0.0510	45.0	0.9633	-0.0387	0.0712	45.0	0.9987	-0.0215	0.0525
60.0	0.7854	-0.0837	0.1406	60.0	0.8281	-0.0283	0.0688	60.0	0.9647	-0.0437	0.0522	60.0	1.0139	-0.0100	0.0484
60.0	0.7751	-0.0844	0.1392	60.0	0.8225	-0.0297	0.0703	60.0	0.9568	-0.0412	0.0512	60.0	1.0071	-0.0269	0.0524
75.0	0.8440	-0.1224	0.1098	75.0	0.9197	-0.0857	0.0849	75.0	0.9979	-0.0600	0.0151	75.0	1.0016	-0.0391	0.0516
75.0	0.8316	-0.1200	0.1079	75.0	0.9148	-0.0841	0.0874	75.0	0.9953	-0.0577	0.0165	75.0	1.0026	-0.0313	0.0535
90.0	0.7854	-0.0827	0.0661	90.0	0.9107	-0.0829	0.0729	90.0	0.9971	-0.0459	0.0480	90.0	1.0179	-0.0249	0.0490
90.0	0.7755	-0.0791	0.0671	90.0	0.9179	-0.0816	0.0751	90.0	0.9953	-0.0451	0.0482	90.0	1.0091	-0.0218	0.0471
105.0	0.7033	-0.0158	0.0592	105.0	0.8974	-0.0616	0.0669	105.0	1.0029	-0.0447	0.0446	105.0	1.0151	-0.0194	0.0455
105.0	0.6919	-0.0184	0.0622	105.0	0.8860	-0.0607	0.0678	105.0	0.9987	-0.0459	0.0453	105.0	1.0089	-0.0272	0.0475
120.0	0.6852	-0.0423	0.0769	120.0	0.8907	-0.0541	0.0623	120.0	1.0018	-0.0442	0.0467	120.0	1.0115	-0.0287	0.0518
120.0	0.6817	-0.0433	0.0765	120.0	0.8856	-0.0542	0.0644	120.0	0.9970	-0.0440	0.0420	120.0	1.0053	-0.0284	0.0496
135.0	0.7012	-0.0568	0.0803	135.0	0.8950	-0.0537	0.0602	135.0	0.9991	-0.0446	0.0413	135.0	1.0119	-0.0296	0.0525
135.0	0.6919	-0.0554	0.0816	135.0	0.8910	-0.0558	0.0620	135.0	0.9961	-0.0452	0.0416	135.0	1.0017	-0.0293	0.0545
150.0	0.7060	-0.0613	0.0799	150.0	0.8954	-0.0566	0.0540	150.0	0.9990	-0.0459	0.0342	150.0	1.0113	-0.0302	0.0499
150.0	0.7033	-0.0607	0.0820	150.0	0.8879	-0.0561	0.0585	150.0	0.9928	-0.0463	0.0368	150.0	1.0063	-0.0301	0.0532
165.0	0.7110	-0.0588	0.0775	165.0	0.8984	-0.0574	0.0493	165.0	0.9952	-0.0456	0.0325	165.0	1.0114	-0.0320	0.0561
165.0	0.7072	-0.0611	0.0851	165.0	0.8897	-0.0575	0.0558	165.0	0.9897	-0.0464	0.0362	165.0	1.0047	-0.0317	0.0506
180.0	0.7144	-0.0653	0.0820	180.0	0.8954	-0.0580	0.0447	180.0	0.9972	-0.0480	0.0265	180.0	1.0129	-0.0322	0.0231
180.0	0.7050	-0.0645	0.0844	180.0	0.8895	-0.0575	0.0495	180.0	0.9902	-0.0480	0.0301	180.0	1.0040	-0.0319	0.0293
195.0	0.7127	-0.0628	0.0819	195.0	0.8969	-0.0593	0.0423	195.0	0.9973	-0.0483	0.0215	195.0	1.0102	-0.0347	0.0216
195.0	0.7128	-0.0655	0.0877	195.0	0.8906	-0.0594	0.0473	195.0	0.9918	-0.0490	0.0266	195.0	1.0051	-0.0365	0.0280
210.0	0.7137	-0.0674	0.0834	210.0	0.8997	-0.0611	0.0336	210.0	0.9958	-0.0489	0.0185	210.0	1.0102	-0.0320	0.0186
210.0	0.7163	-0.0697	0.0826	210.0	0.9005	-0.0618	0.0361	210.0	0.9944	-0.0492	0.0202	210.0	1.0049	-0.0336	0.0213
225.0	0.7120	-0.0688	0.0849	225.0	0.8946	-0.0589	0.0349	225.0	0.9926	-0.0500	0.0190	225.0	1.0051	-0.0341	0.0192
225.0	0.7120	-0.0688	0.0849	225.0	0.8946	-0.0589	0.0349	225.0	0.9926	-0.0500	0.0190	225.0	1.0051	-0.0341	0.0192
240.0	0.7105	-0.0682	0.0817	240.0	0.8955	-0.0580	0.0273	240.0	0.9966	-0.0488	0.0121	240.0	1.0113	-0.0313	0.0107
240.0	0.7127	-0.0701	0.0805	240.0	0.8993	-0.0604	0.0313	240.0	0.9933	-0.0494	0.0143	240.0	1.0074	-0.0327	0.0131
255.0	0.7021	-0.0678	0.0779	255.0	0.8993	-0.0586	0.0219	255.0	0.9964	-0.0478	0.0107	255.0	1.0094	-0.0304	0.0101
255.0	0.6979	-0.0684	0.0786	255.0	0.8987	-0.0572	0.0219	255.0	0.9929	-0.0480	0.0121	255.0	0.9979	-0.0305	0.0110
270.0	0.6729	-0.0635	0.0705	270.0	0.8910	-0.0541	0.0201	270.0	0.9951	-0.0465	0.0095	270.0	1.0116	-0.0290	0.0059
270.0	0.6770	-0.0662	0.0689	270.0	0.8952	-0.0553	0.0191	270.0	0.9927	-0.0471	0.0082	270.0	1.0113	-0.0300	0.0056
285.0	0.6191	-0.0492	0.0512	285.0	0.8789	-0.0508	0.0157	285.0	0.9918	-0.0456	0.0050	285.0	1.0095	-0.0245	0.0073
285.0	0.6221	-0.0502	0.0567	285.0	0.8817	-0.0529	0.0168	285.0	0.9894	-0.0460	0.0056	285.0	1.0009	-0.0274	0.0064
300.0	0.5913	-0.0166	0.0617	300.0	0.8574	-0.0500	0.0110	300.0	0.9874	-0.0444	0.0060	300.0	1.0148	-0.0212	0.0072
300.0	0.5988	-0.0404	0.0631	300.0	0.8599	-0.0532	0.0131	300.0	0.9846	-0.0448	0.0062	300.0	1.0033	-0.0218	0.0065
315.0	0.6312	-0.0604	0.0813	315.0	0.8324	-0.0566	0.0104	315.0	0.9714	-0.0451	0.0033	315.0	1.0091	-0.0203	0.0084
315.0	0.6348	-0.0631	0.0815	315.0	0.8331	-0.0577	0.0121	315.0	0.9713	-0.0453	0.0027	315.0	1.0134	-0.0205	0.0087
330.0	0.6755	-0.1012	0.0836	330.0	0.8127	-0.0708	0.0169	330.0	0.9297	-0.0484	0.0017	330.0	1.0037	-0.0245	0.0113
330.0	0.6819	-0.1043	0.0821	330.0	0.8202	-0.0729	0.0154	330.0	0.9314	-0.0489	0.0019	330.0	0.9978	-0.0247	0.0119
345.0	0.6832	-0.1105	0.0821	345.0	0.7302	-0.0626	0.0282	345.0	0.7792	-0.0352	0.0003	345.0	0.8034	-0.0195	0.0059
345.0	0.6870	-0.1116	0.0789	345.0	0.7420	-0.0651	0.0224	345.0	0.7693	-0.0326	0.0009	345.0	0.7953	-0.0212	0.0075

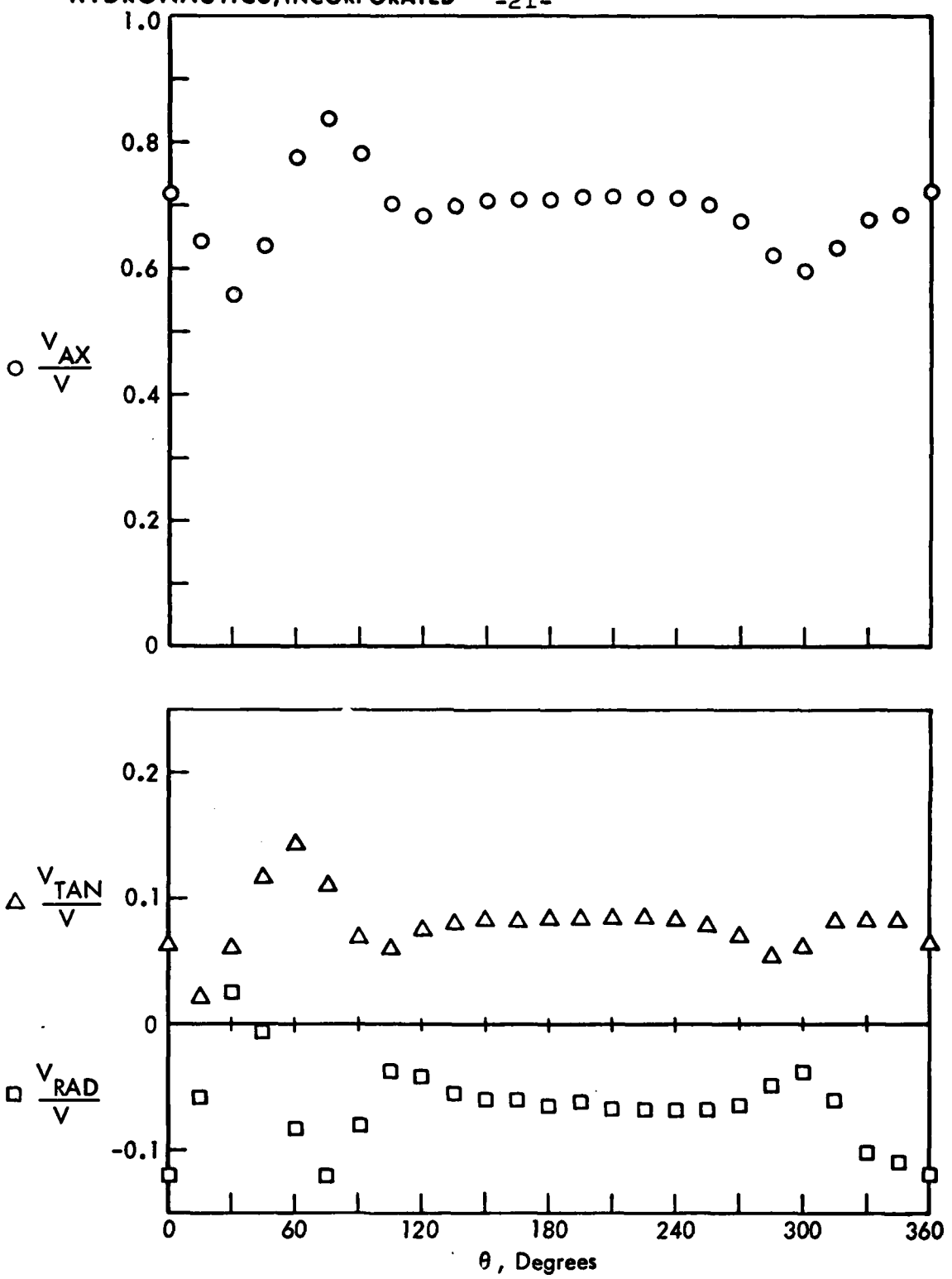


FIGURE 6 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR SWATH VII - APPENDED AT $r/r_h = 0.375$

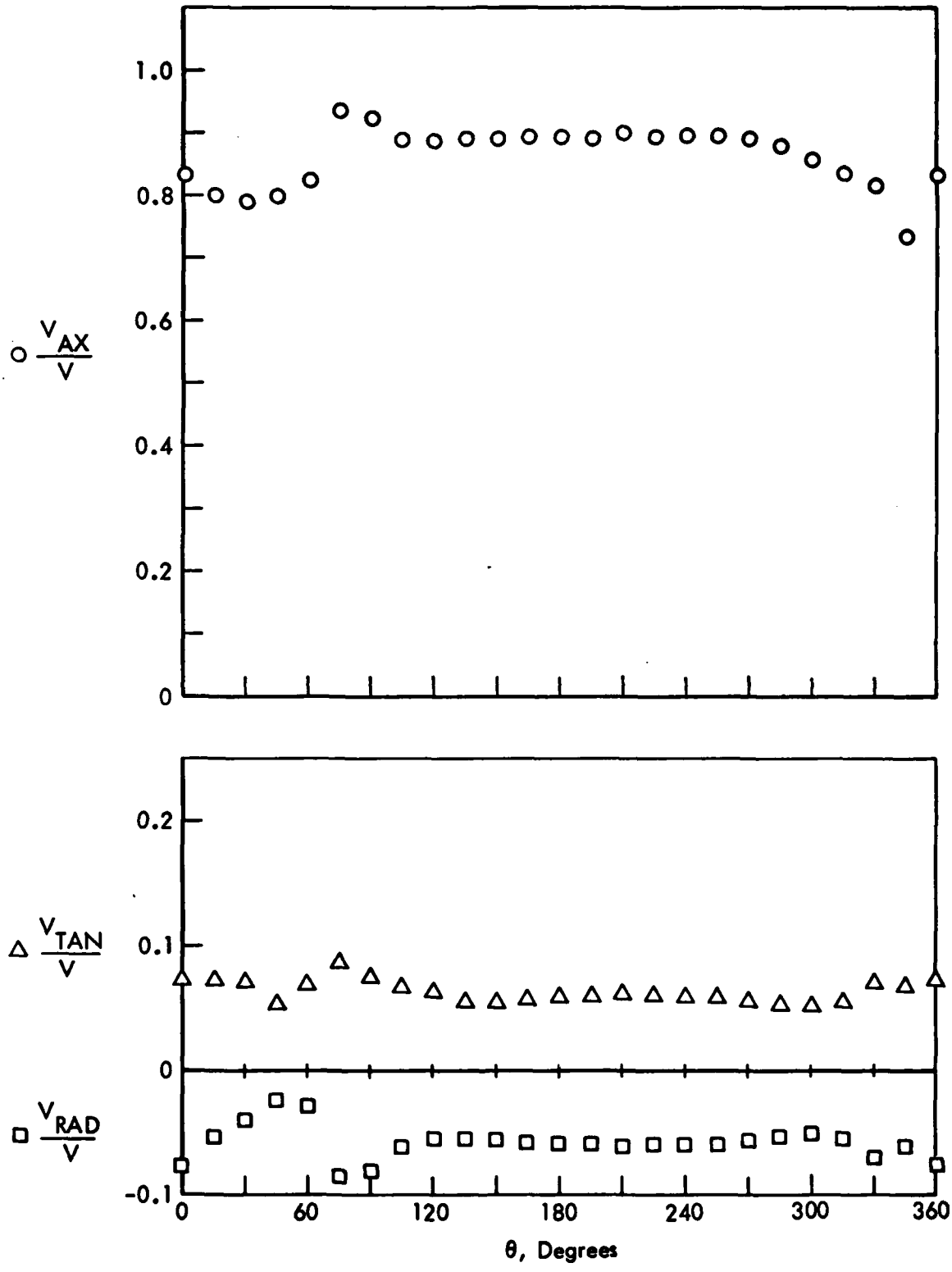


FIGURE 7 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR SWATH VII - APPENDED AT $r/r_h = 0.675$

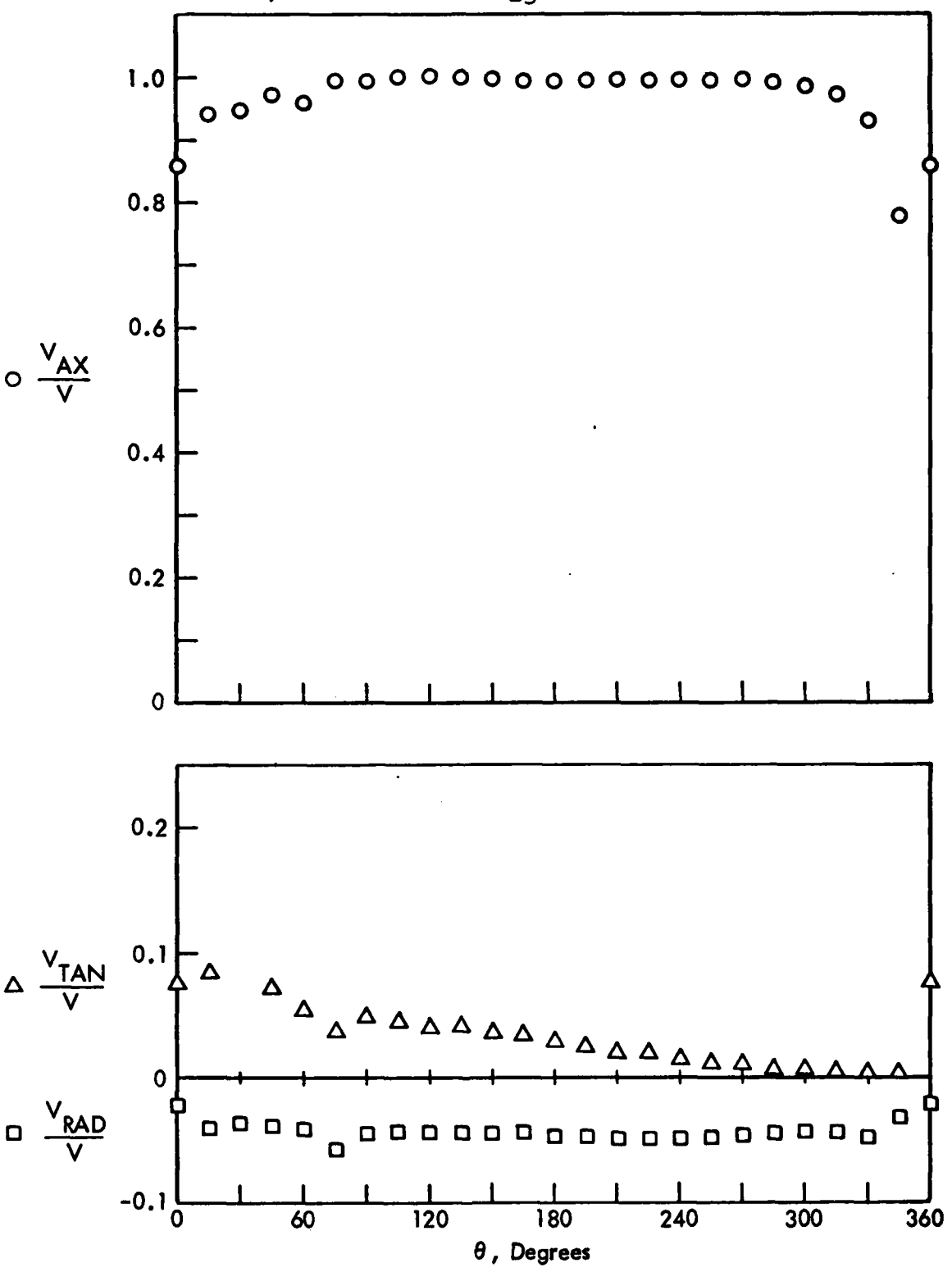


FIGURE 8 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR SWATH VII - APPENDED AT $r/r_h = 0.975$

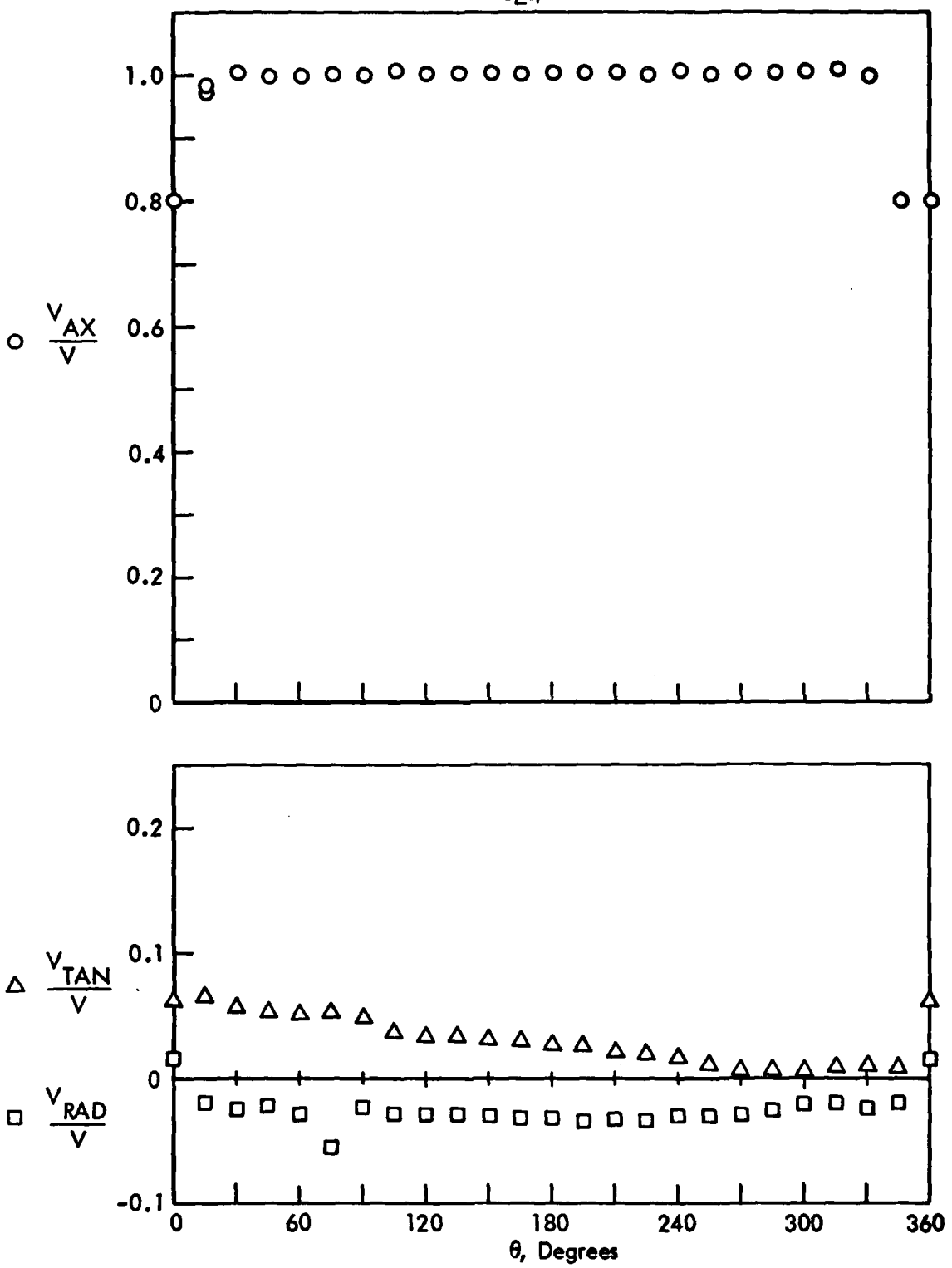


FIGURE 9 - CIRCUMFERENTIAL VARIATION OF WAKE VELOCITY FOR SWATH VII - APPENDED AT $r/r_h = 1.275$

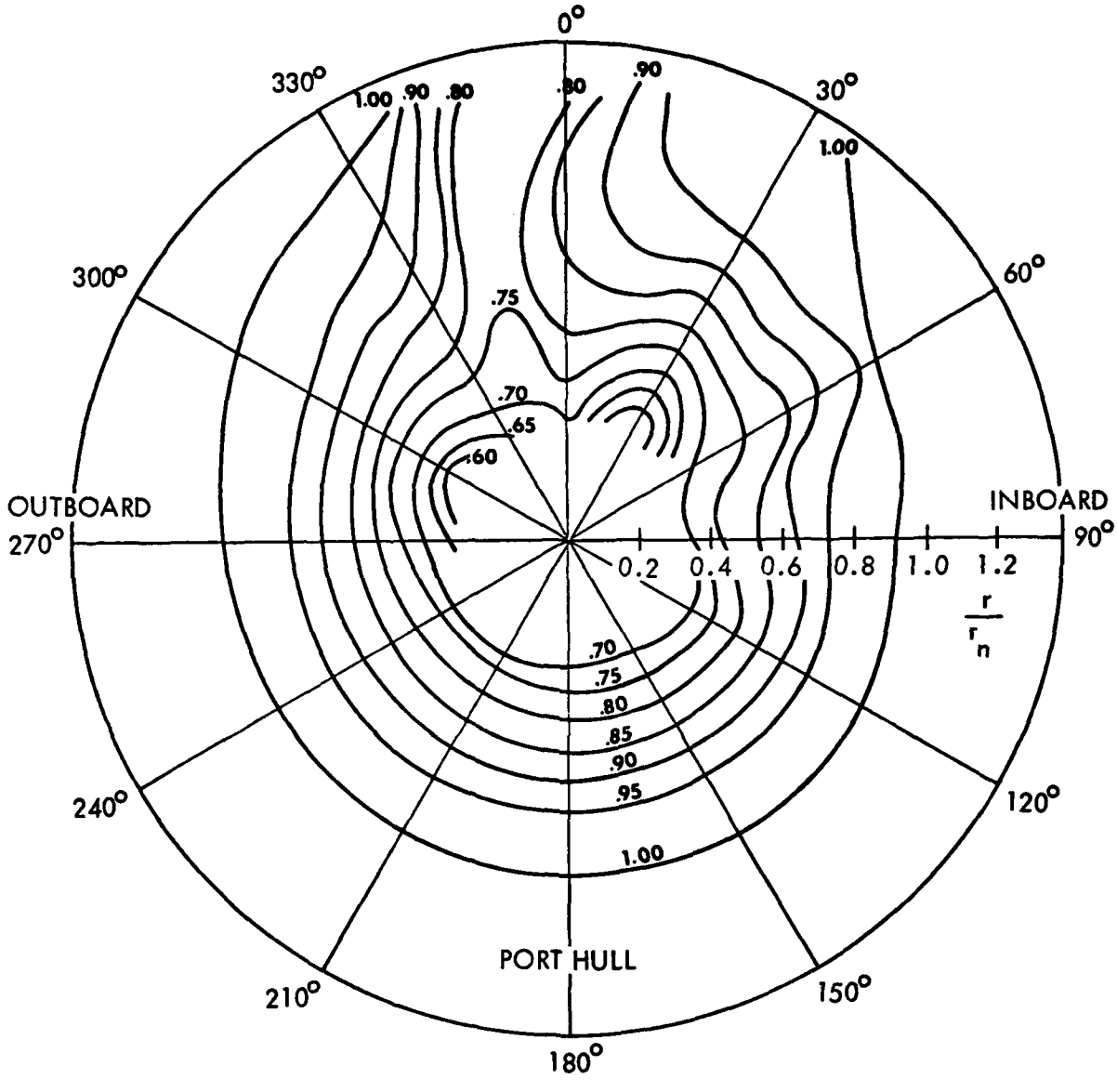


FIGURE 10 - CONTOUR MAP OF LONGITUDINAL VELOCITY COMPONENTS IN THE PROPELLER PLANE FOR SWATH VII - APPENDED

ENGINEERING STUDIES

General

The experimental program described herein was devoted primarily to predictions of the SWATH resistance. However, speed power performance is also greatly affected by propulsor characteristics. Therefore, a number of engineering studies were carried out as described in the following sections to augment the resistance experiments for arriving at performance predictions.

Specific Propeller Designs

In accordance with Reference 1, propeller parametric designs were carried out for two particular propellers having diameter/hull diameter ratios of 0.90 and 1.10. These were tailored to the EHP and wake characteristics of SWATH VII at 20 knots. For each propeller, the BAR was selected based upon cavitation considerations, and an arbitrary thickness distribution was selected so as to give conservative stress levels. Using these, and a variety of pitch distributions, calculations of the propulsive coefficient were made for a range of shaft rpm values. The results are shown in Figure 11 for Propeller 7694-90 and in Figure 12 for Propeller 7694-110. The assumed hull/propeller interaction factors are also shown. Open water efficiencies are not shown because these are wake adapted propellers. Details of the calculations and the propeller configurations are given in Appendix C. From this range of designs, the maximum propulsive efficiency was designated as the optimum. The characteristics of these two propellers are given in Table 8. Of course,

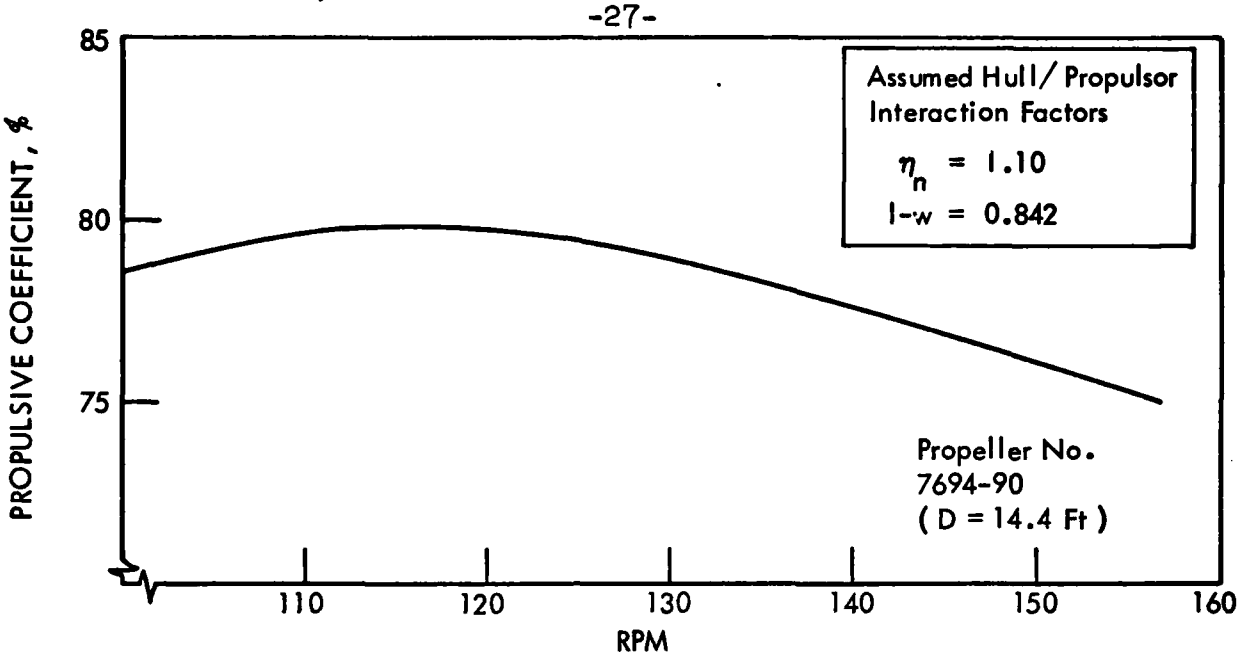


FIGURE 11 - VARIATION OF PROPULSIVE COEFFICIENT WITH RPM FOR PROPELLER 7694-90

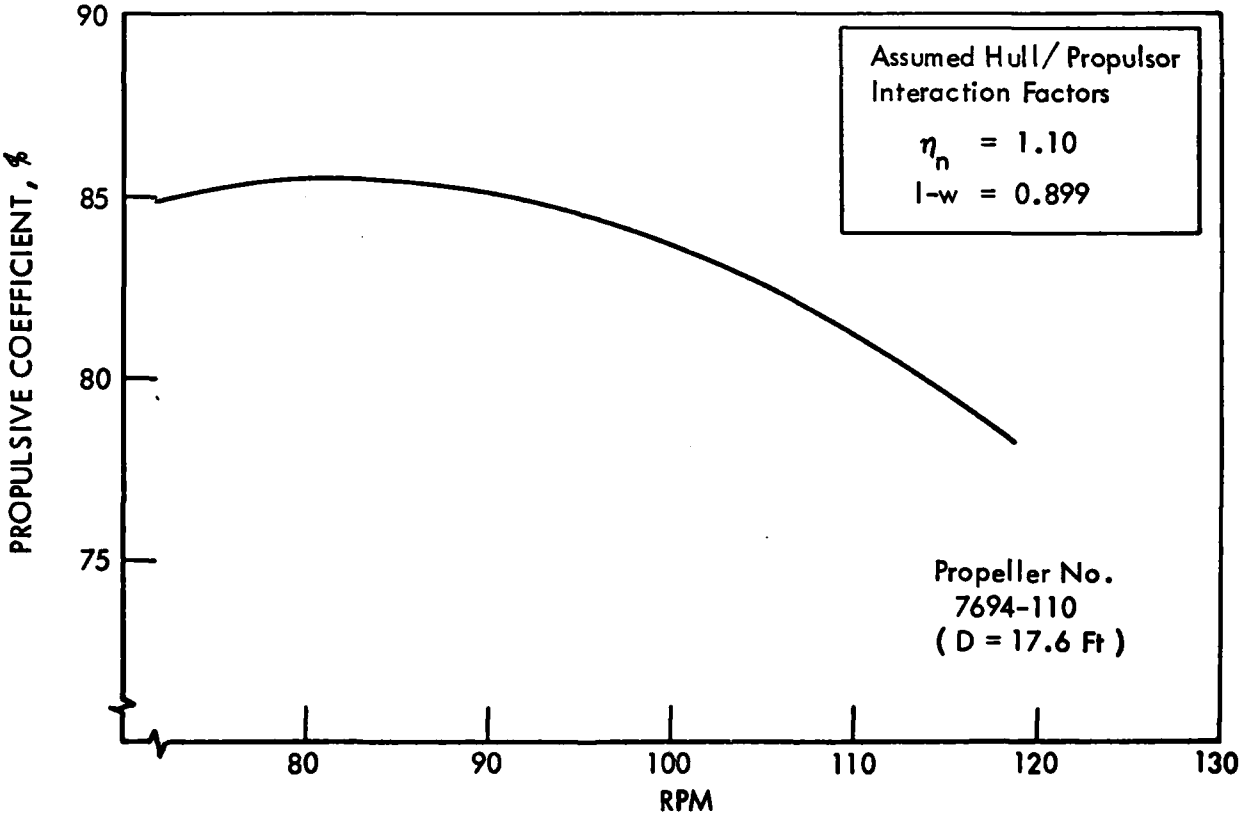


FIGURE 12 - VARIATION OF PROPULSIVE COEFFICIENT WITH RPM FOR PROPELLER 7694-110

Table 8

Characteristics of Specific Propeller Designs Wake Adapted to SWATH VII

Characteristic	7694-90	7694-110	7694-110-36
Diameter/Hull Diameter Ratio	0.90	1.10	1.10
Diameter, Feet	14.4	17.6	17.6
BAR	0.55	0.50	0.78
Optimum RPM	117	82	130

other considerations will ultimately enter into the propeller design optimization.

Effects of Diameter Variation

In addition to the two specific propeller designs previously described, a family of other props were investigated in less detail to gain insight into the efficiency variation with changes in diameter at optimum rpm values. The estimated propulsive efficiencies and rpm values for this family are shown in Figure 13.

Off-Design Propeller Performance

Subsequent to the diameter and RPM variation studies described above, two propellers having diameter/hull diameter ratios of 1.1 were investigated at off-design. One of these was the 20-knot design propeller designated 7694-110, and a new design was performed designated 7694-110-36 for operation at 36-knots. The characteristics of this propeller are also given in Table 8. The operating RPM of this second propeller was chosen as 130 with a drag of 28,575 kgs. A lower RPM (higher J) would have more favorable cavitation characteristics, but an impractically high pitch-diameter ratio. The off-design performance of these two propellers is given in Figures 14 and 15 and in Table 9. Supplemental design data for propeller 7694-110-36 is given in Appendix C.

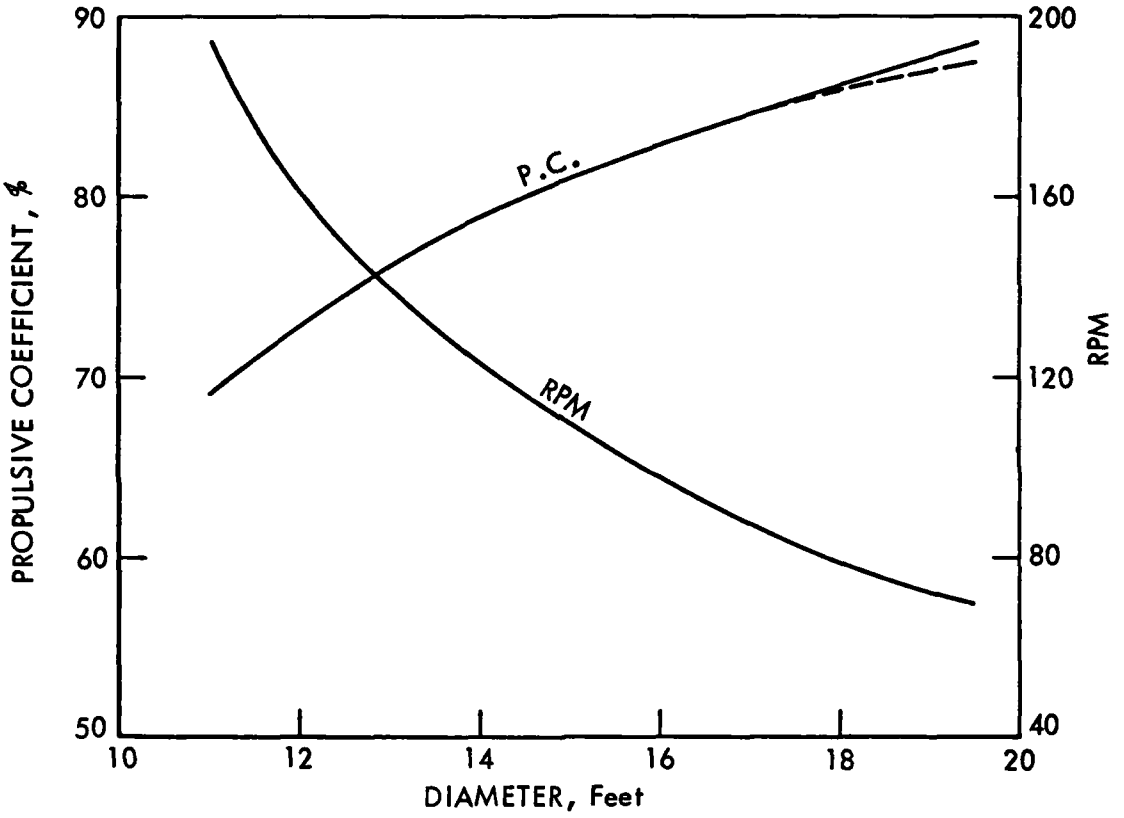


FIGURE 13 - VARIATION OF OPTIMUM P.C. AND RPM WITH DIAMETER FOR SWATH VII SHIP AT 20 KNOTS

NOTE: The solid line represents the calculated values of P.C. for a constant value (1.10) of η_H for all diameters - giving (1-t)>1 for large diameters. In reality, (1-t) should level off at 1 for large diameters giving P.C. as indicated by broken line. (Self-propulsion tests with large propellers would give correct estimates of thrust-deduction in those cases.)

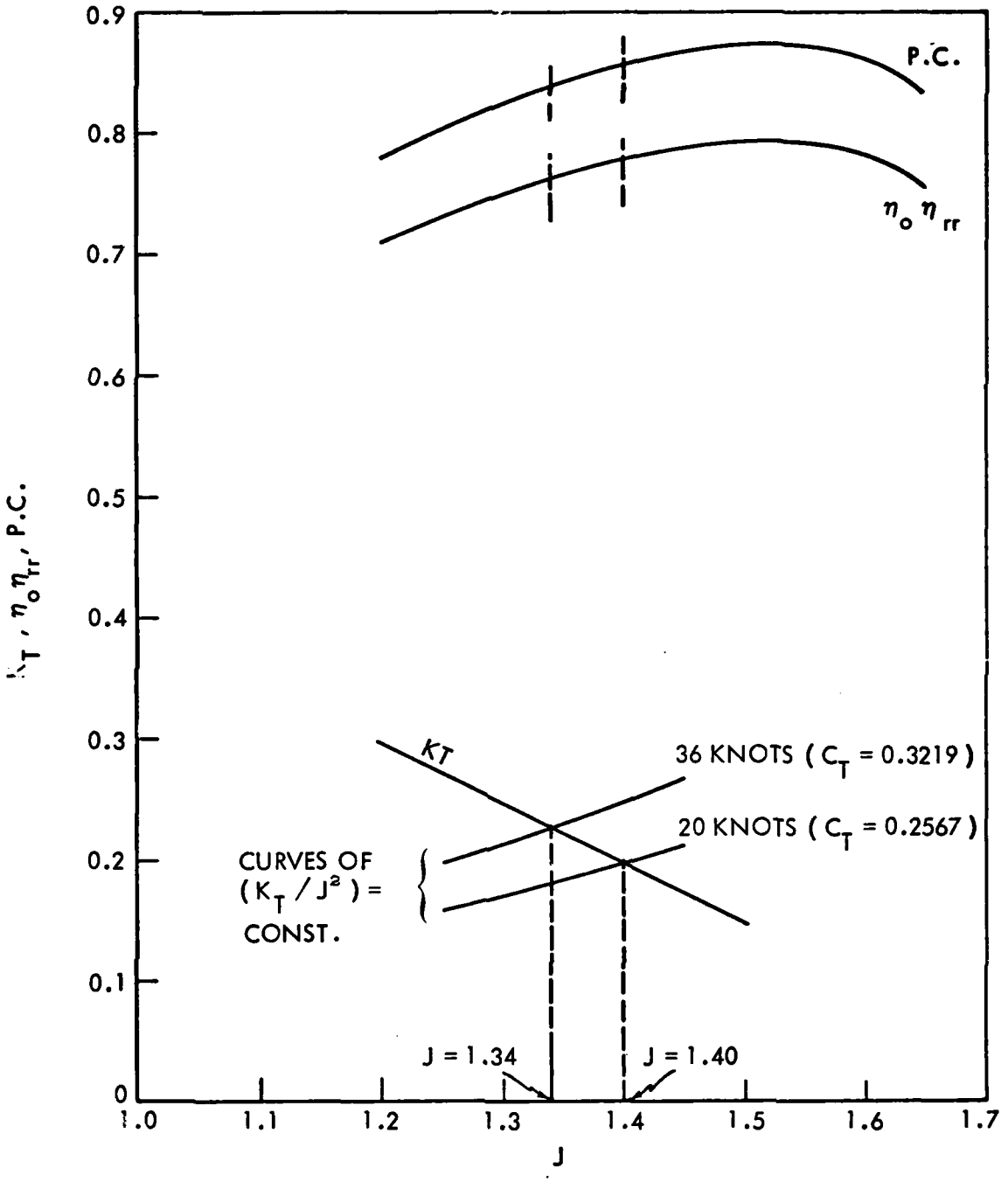


FIGURE 14 - PREDICTED PERFORMANCE OF PROPELLER 7694-110 FOR SWATH VII

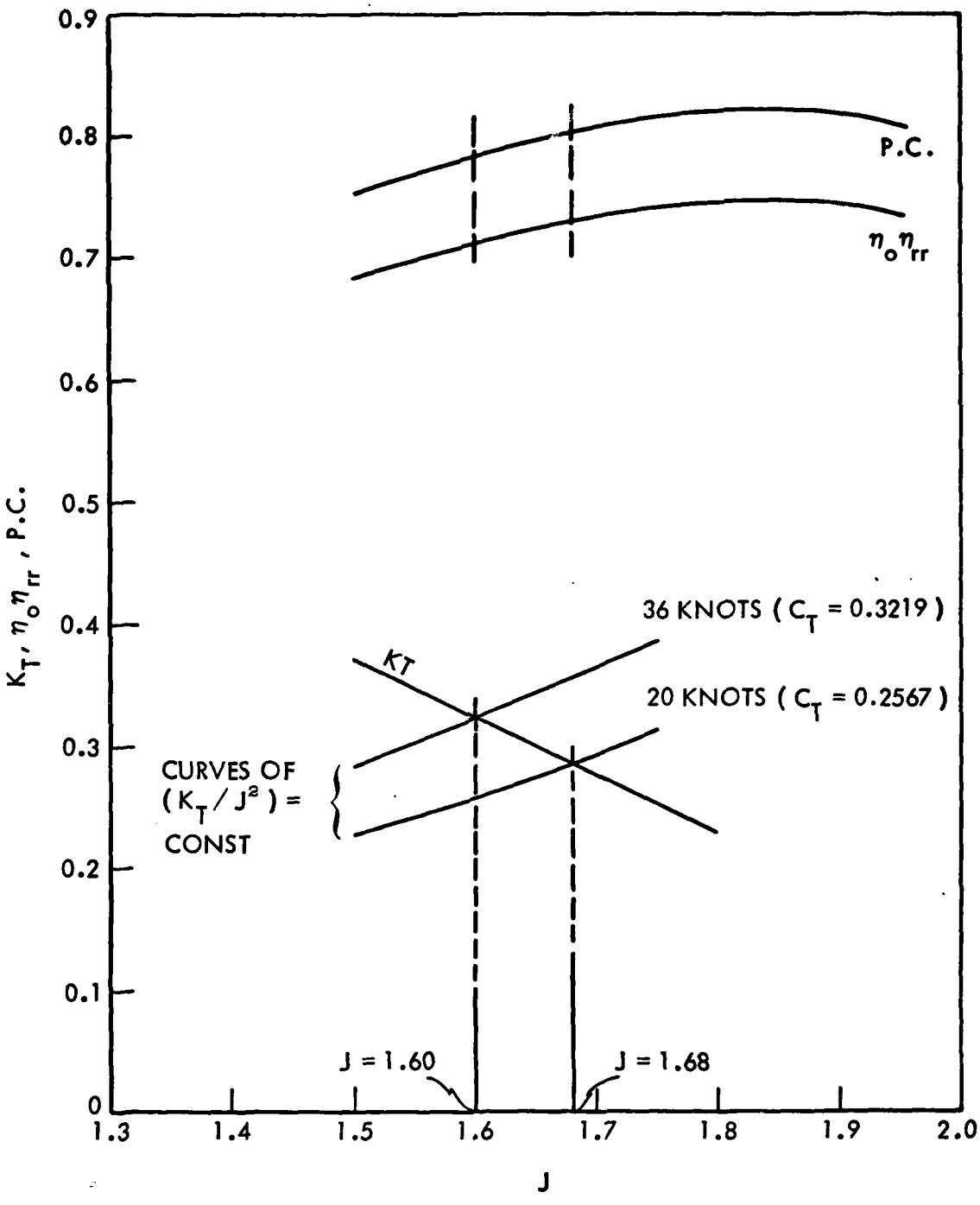


FIGURE 15 - PREDICTED PERFORMANCE OF PROPELLER 7694-110-36 FOR SWATH VII

TABLE 9

Performance of Propellers 7694-110
and 110-36 at Off-Design Speeds

Prop. No.	Design Speed	Off-Design Speed (knots)	RPM	P.C.	Cav. Margin at .7R	Gawn-Burrill Coeffs. at .7R[1]	Extent of Cavitation
7694-110	20	36	155	0.837[2]	0.818	τ = .256 σ = .261	50% or more of blade surface
7694-110-36	36	20	69	0.803	5.427	τ = .204 σ = 1.173	Virtually none

[1]Gawn-Burrill coefficients are calculated using the mean wake of 0.1006.
[2]This P.C. value has no meaning because of thrust breakdown not accounted for in the calculations.

Extraordinary Machinery Operating Conditions

The study for locked and free-wheeling shaft, as well as the calculation of power required to keep one propeller at zero thrust were carried out using four-quadrant data published in Reference 3.

In the cases of locked and free-wheeling shaft, the optimum pitch is the highest obtainable. For the purpose of calculations, this was assumed to be 120 percent of design pitch. The four-quadrant thrust and torque coefficients are defined as:

$$C_T' = T/\tfrac{1}{2}\rho[V_A^2 + (.7\pi nD)^2]A \ ,$$

and

$$C_Q' = Q/\tfrac{1}{2}\rho[V_A^2 + (.7\pi nD)^2]AD \ ,$$

where

T: thrust

Q: torque

ρ: density of water

V_A: velocity of advance

n: rps

D: propeller diameter

A: propeller disk area

Inflow angle, $\beta = \arctan (V_A/.7\pi nD)$

The locked-shaft drags were calculated using C_T' as given in the four-quadrant data, for the appropriate pitch-ratios, and zero rotational speed (i.e., for $\beta = 90^\circ$). (C_T' is negative at $\beta = 90^\circ$ and, therefore, it gives negative thrust – i.e., drag.) The results of these calculations are given in Table 10.

In the case of free-wheeling propeller, the assumed torque was 1 percent of full power torque.

For a range of β, values of C_Q' were plotted on the four-quadrant data chart using this value of Q; the value of β corresponding to the appropriate pitch-diameter ratio was picked and the corresponding rotational speed was calculated.

The value of C_T' corresponding to this combination of pitch and β was obtained from four-quadrant data chart, and the drag was calculated using this C_T'. The results of these calculations are given in Table 11.

In order to calculate the power required to keep one shaft at zero thrust, values of β and C_Q' were picked from four-quadrant data chart at $C_T' = 0$. The rotational speed corresponding to this value of β was calculated. The torque, Q, was then calculated to give the power. The results of these calculations are given in Table 12.

TABLE 10

SWATH VII Performance,
One Locked Shaft at 20 Knots

Prop. No.	Drag (Kgs)
7694-110	39009
7694-110-36	50670

TABLE 11

SWATH VII Performance,
One Free-Wheeling Shaft at 20 Knots

Prop. No.	Assumed Torque	Drag (Kgs)
7694-110	1% of torque on one shaft at 20 knots	9525
7694-110-36	1% of torque on one shaft at 20 knots	10140
7694-110-36	1% of torque on one shaft at 36 knots	17790

TABLE 12

SWATH VII Performance,
Power Required to Keep One Shaft
at Zero Thrust at 20 Knots

Prop. No.	Required Power (SHP)
7694-110	770 (15% of one shaft power at 20 knots)
7694-110-36	960 (18% of one shaft power at 20 knots)

REFERENCES

1. Contract N00600-76-C-1393

2. Gertler, Kohl and Kirkman, "Experimental Investigation of a Systematic Series of Low Length-Beam Ratio, High Block Coefficient Merchant Ship Forms," HYDRONAUTICS, Incorporated Technical Report 7166-1, June 1973.

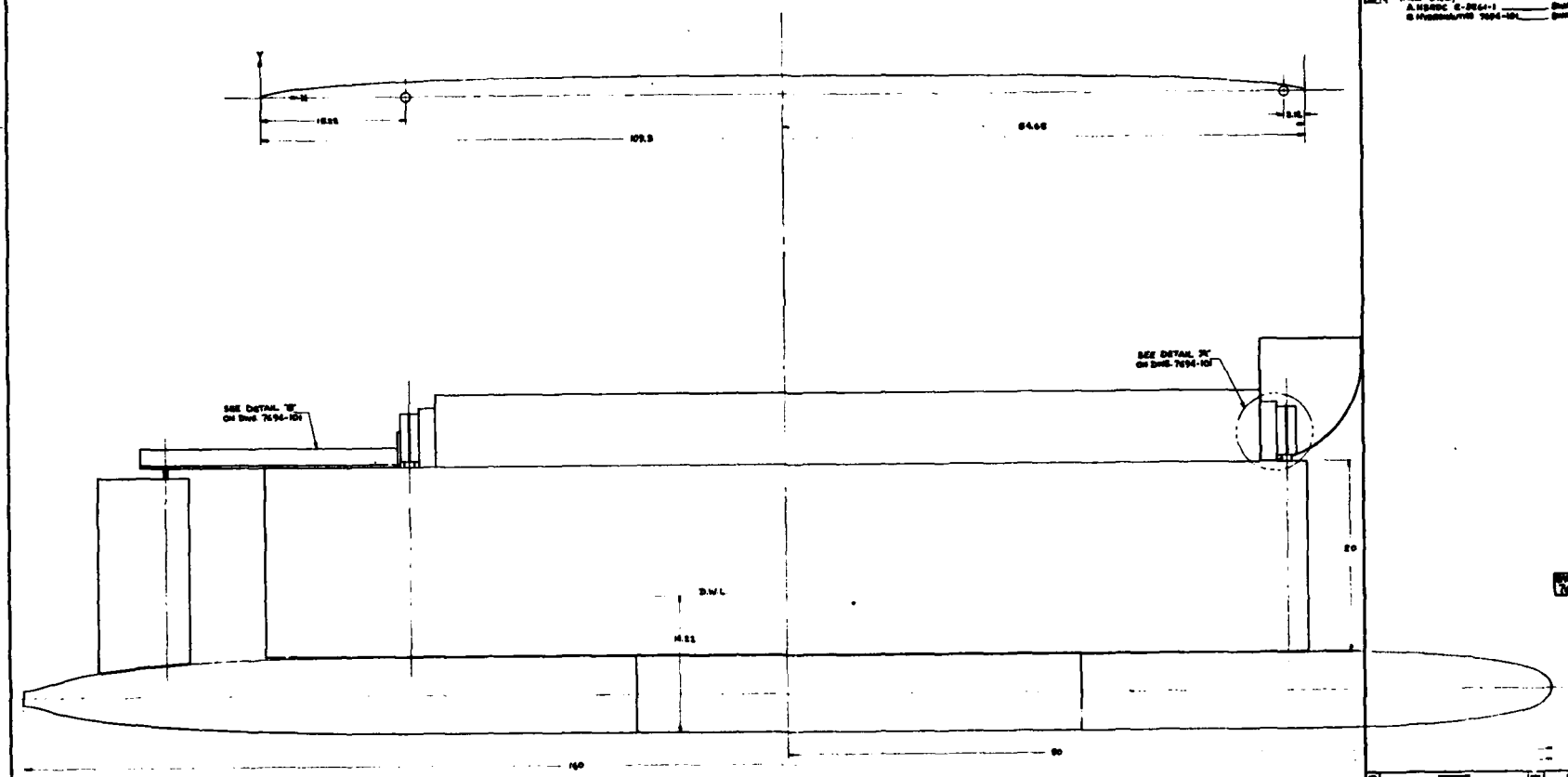
3. "Prediction of Controllable-Pitch Propeller Performance in Off-Design Conditions," J. Strom-Tejsen and R. R. Porter, Paper VII B-1, Third Ship Control Systems Symposium, Ministry of Defence, Foxhill, Berth, Somerset, U.K.

APPENDIX A
MODEL DRAWINGS

DWG. NO. 7694-100

STRUT OFFSETS

X Dim	Y Dim
0.0	0.0
1.093	.434
2.186	.614
3.277	.700
5.463	.864
10.925	1.387
16.388	1.697
21.850	1.704
32.775	1.841
43.700	1.870
54.625	1.878



NOTE: 1. REF DWG.,
A. HSRDC E-3561-1 ——— SWATH ASSEMBLY
B. HYDRONAUTICS 7694-101 ——— SWATH DETAILS

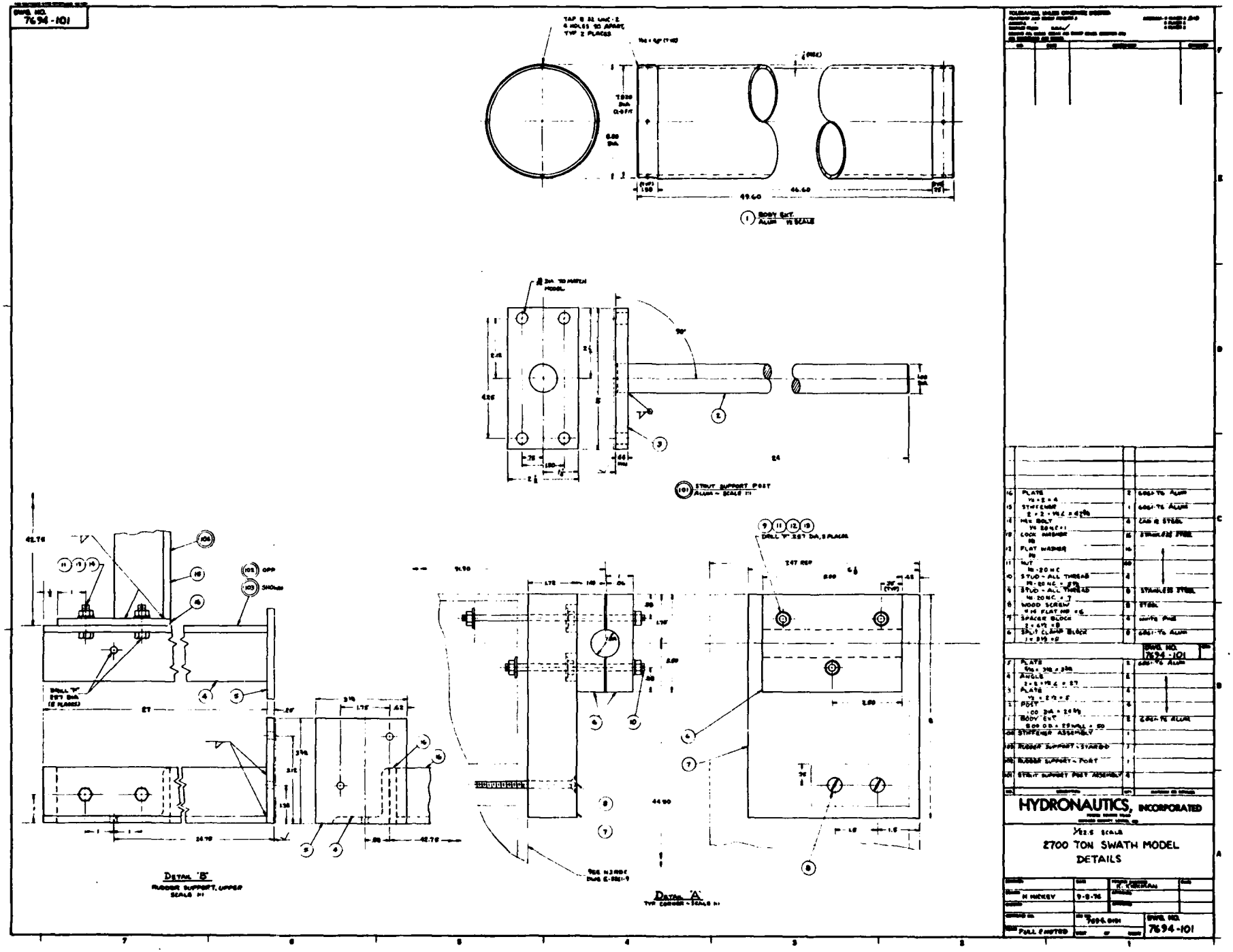
DWG. NO. 7694-100

HYDRONAUTICS, INCORPORATED

1/22.5 SCALE

2700 TON SWATH MODEL
GENERAL ARRANGEMENT

H. HICKEY	9-7-76	KARL KIRKMAN	
		7694-0131	DWG. NO. 7694-100


DWG. NO. 7694-101
BODY EXT. ALUM 1/2 SCALE
STRUT SUPPORT POST ALUM ~ SCALE 1:1
DETAIL 'B' RUDDER SUPPORT, UPPER SCALE 1:1
DETAIL 'A' TYP CORNER ~ SCALE 1:1
HYDRONAUTICS, INCORPORATED
1/22.5 SCALE
2700 TON SWATH MODEL
DETAILS
DWG. NO. 7694-101

APPENDIX B

MODEL RESIDUARY RESISTANCE COEFFICIENTS

B-1 - Residuary Resistance Coefficient Test Data for SWATH VI-A - Fully Appended (Model 7694-1)

B-2 - Residuary Resistance Coefficient Test Data for SWATH VII - Bare Hull (Model 7694-2)

B-2 - Residuary Resistance Coefficient Test Data for SWATH VII - Fully Appended (Model 7694-2)

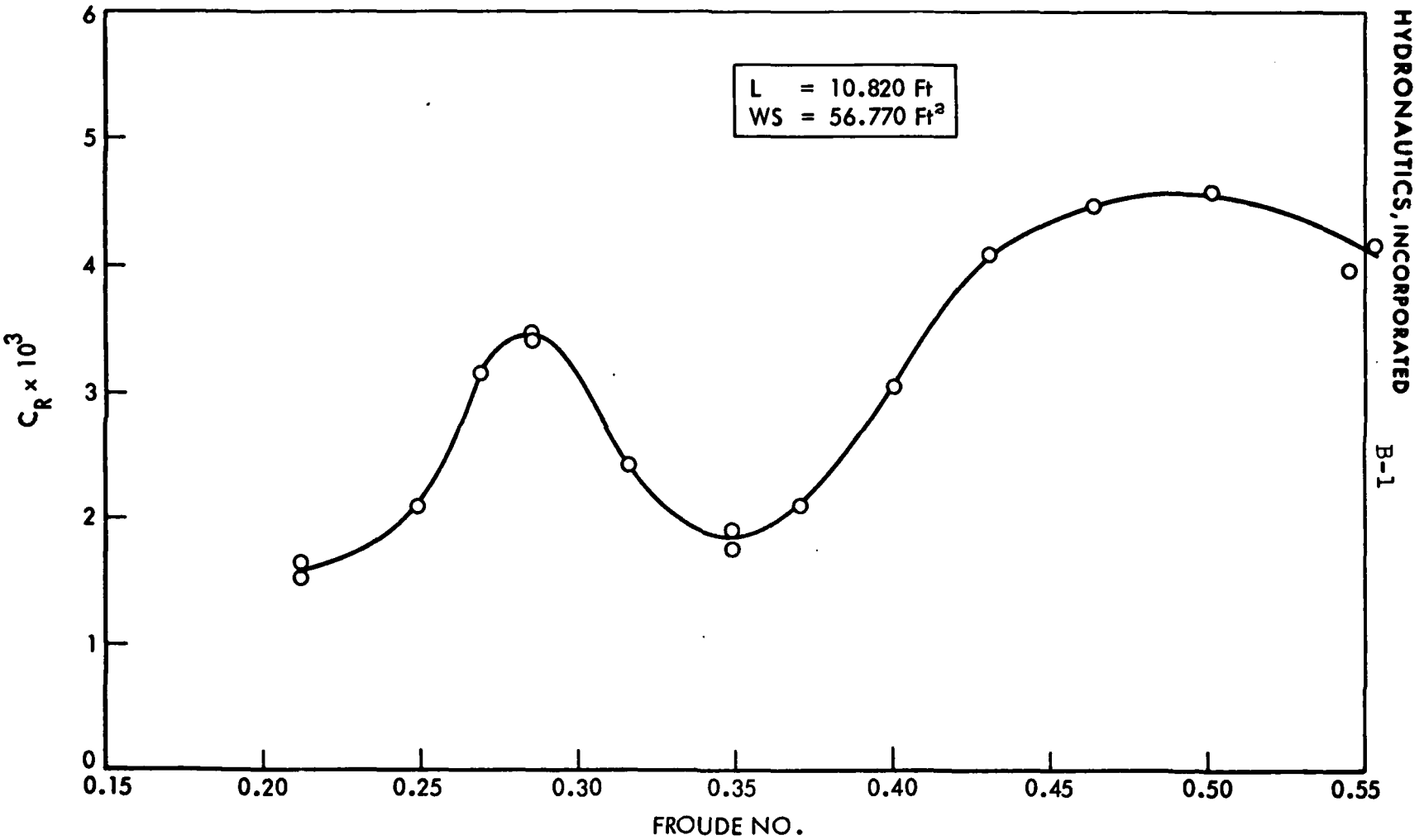


FIGURE B-1 - RESIDUARY RESISTANCE COEFFICIENT TEST DATA FOR SWATH VI-A - FULLY APPENDED (MODEL 7694-1)

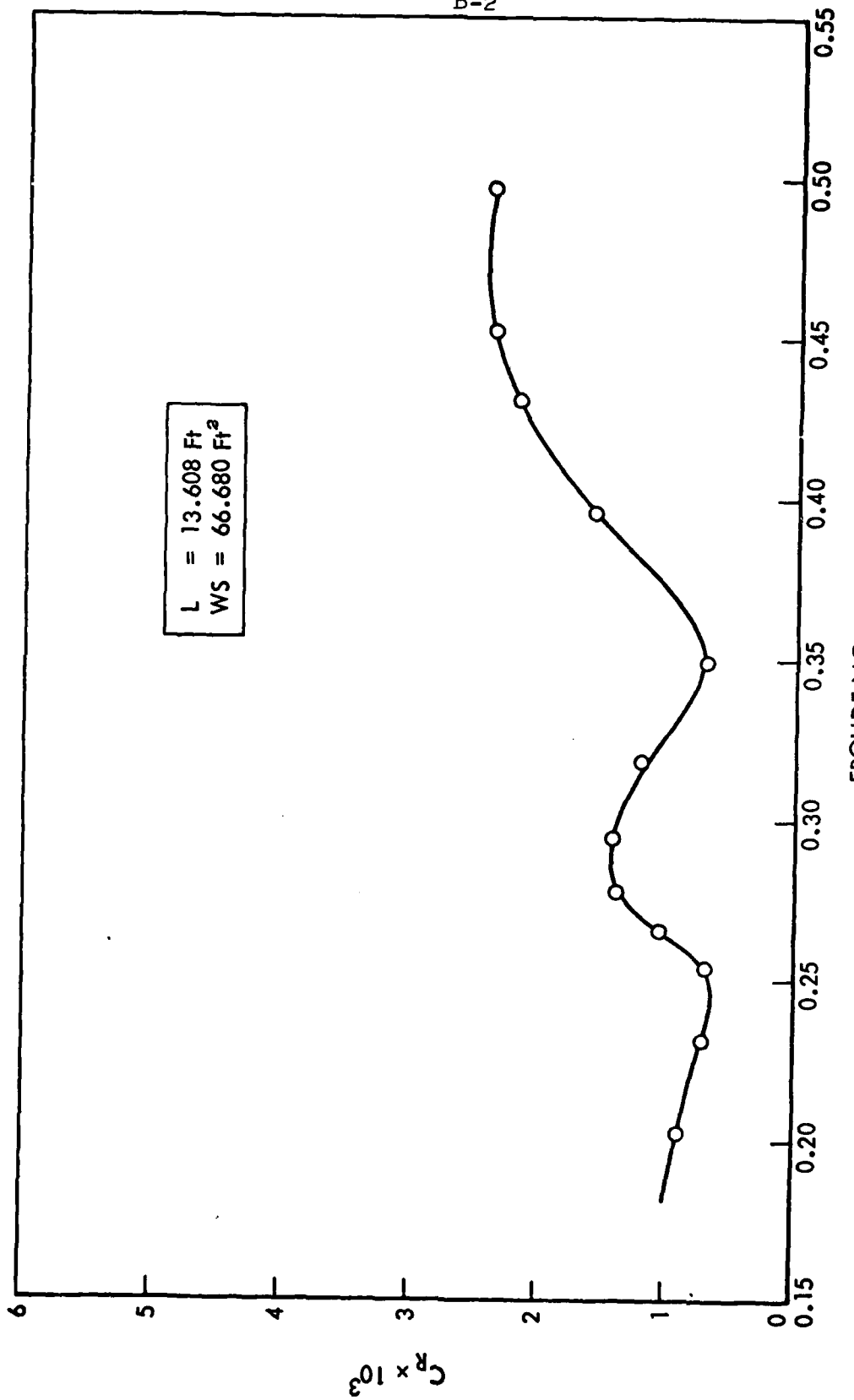


FIGURE B-2 – RESIDUARY RESISTANCE COEFFICIENT TEST DATA FOR SWATH VII – BARE HULL (MODEL 7694-2)

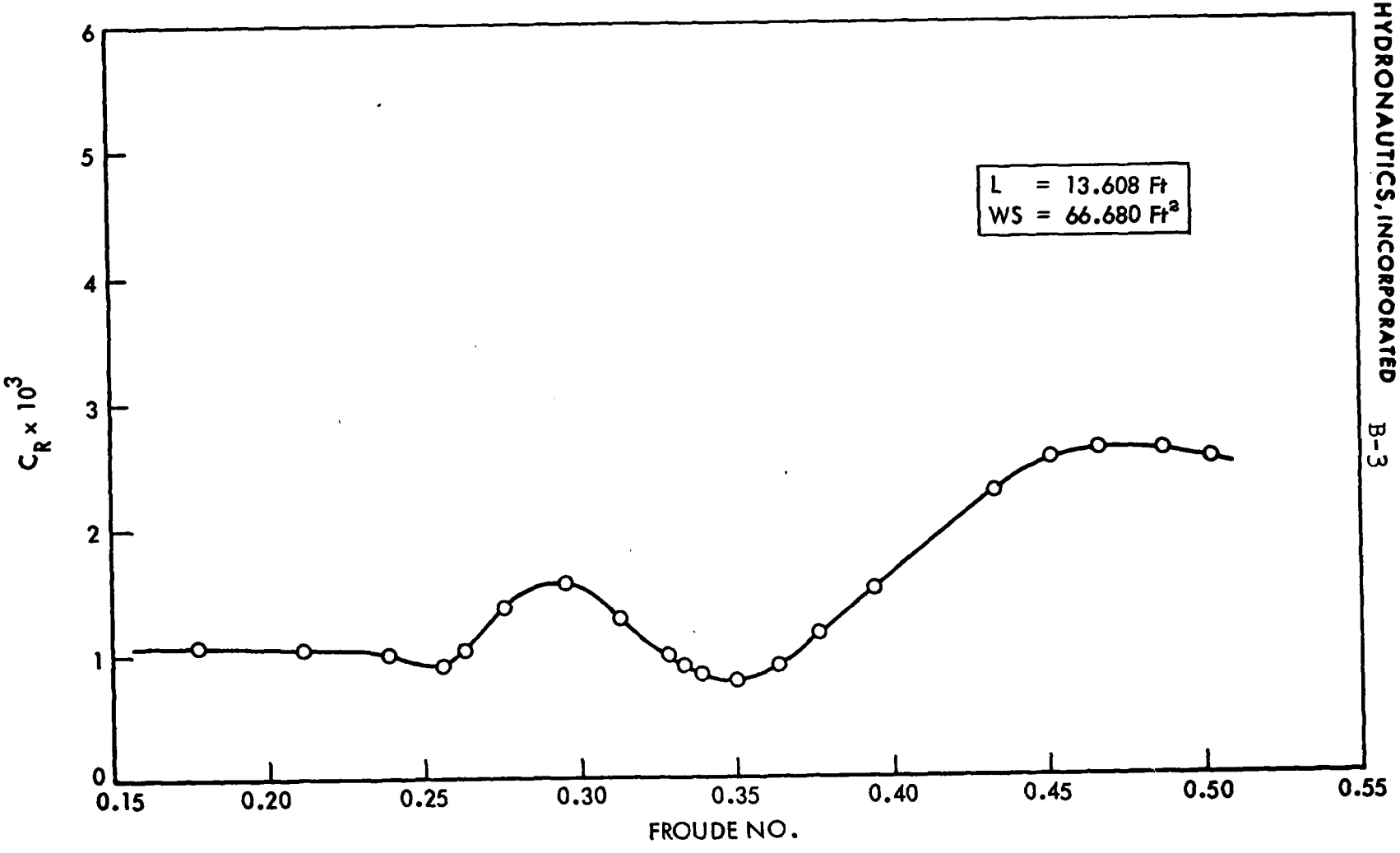


FIGURE B-3 - RESIDUARY RESISTANCE COEFFICIENT TEST DATA FOR SWATH VII - FULLY APPENDED (MODEL 7694-2)

APPENDIX C

DETAILS OF PROPELLER DESIGNS

HYDRONAUTICS INC. *** PROPELLER DESIGN PROGRAM 192 *** PROPELLER NUMBER 7604 00
(ARBITRARY CIRCULATION LIFTING LINE *** VERSION 7, FEB.1975)

HYDRONAUTICS, INCORPORATED

-C1-

1.2000 J	CT = 0.4095	CTI = 0.4221	MAX CHORD AT 0.640R	0.0370 T/D AT 0.300R
0.3819 LAMBDA	CP = 0.4754	CPI = 0.4473	ROOT CHORD IS 0.550	0.0230 T/D AT 0.600R
0.3000 HUB RADIUS	KT = 0.2315	KTI = 0.2387	OF MAX CHORD	0.0100 T/D AT 0.900R
5.0000 BLADES	KQ = 0.0513	KQI = 0.0483	SIG-T = 2.3800 * T/C	0.0400 T/C MIN
0.5500 EAR	ETA= 0.8613	ETAI= 0.9437	SIG-L = 0.5560 * CL	0.0100 CD AT ROOT
				0.0080 CD AT TIP
				2.9600 ADVANCE SIGMA
				0.4095 CT REQUIRED
				1.0308 CTI/CT

R/RO	0.2999	0.3468	0.4749	0.6499	0.8249	0.9531	1.0000
CIRCG	0.0000	0.5000	0.8600	0.9800	0.7900	0.4000	0.0000
FAIRED	0.0000	0.4923	0.8678	0.9796	0.7828	0.4073	0.0000
AWAKE	0.3880	0.3570	0.2700	0.1730	0.1000	0.0580	0.0480
TWAKE	0.0280	0.0220	0.0200	0.0120	0.0110	0.0100	0.0090

R/RO	C/D	100*T/D	T/C	UT/2V	UA/2V	VT/V	CL	100*CD	CL*C/D	CT	CP	ETAB
0.300	0.1645	3.7000	0.2249	0.1260	0.0908	0.9454	0.0005	1.0000	0.0001	-0.0006	0.0005	-1.1178
0.350	0.2063	3.4465	0.1671	0.1329	0.1145	1.0749	0.3635	0.9857	0.0749	0.0379	0.0367	0.9472
0.400	0.2377	3.2018	0.1347	0.1360	0.1344	1.2064	0.3925	0.9714	0.0933	0.0623	0.0628	0.9516
0.450	0.2614	2.9655	0.1134	0.1358	0.1503	1.3389	0.3826	0.9571	0.1000	0.0854	0.0893	0.9507
0.500	0.2789	2.7370	0.0981	0.1330	0.1623	1.4716	0.3606	0.9429	0.1006	0.1069	0.1156	0.9479
0.550	0.2908	2.5155	0.0865	0.1279	0.1705	1.6042	0.3345	0.9286	0.0973	0.1262	0.1403	0.9438
0.600	0.2974	2.3000	0.0773	0.1210	0.1751	1.7364	0.3077	0.9143	0.0915	0.1423	0.1620	0.9388
0.650	0.2990	2.0893	0.0699	0.1128	0.1761	1.8681	0.2818	0.9000	0.0842	0.1547	0.1797	0.9329
0.700	0.2952	1.8816	0.0637	0.1036	0.1738	1.9992	0.2575	0.8857	0.0760	0.1627	0.1921	0.9261
0.750	0.2858	1.6744	0.0586	0.0937	0.1684	2.1297	0.2353	0.8714	0.0672	0.1659	0.1986	0.9185
0.800	0.2699	1.4638	0.0542	0.0834	0.1602	2.2597	0.2153	0.8571	0.0581	0.1637	0.1981	0.9102
0.850	0.2459	1.2433	0.0506	0.0729	0.1493	2.3892	0.1978	0.8429	0.0486	0.1551	0.1893	0.9012
0.900	0.2108	1.0000	0.0474	0.0626	0.1363	2.5183	0.1827	0.8286	0.0385	0.1380	0.1694	0.8919
0.925	0.1869	0.8615	0.0461	0.0575	0.1291	2.5827	0.1760	0.8214	0.0329	0.1247	0.1535	0.8871
0.950	0.1563	0.7011	0.0448	0.0525	0.1214	2.6470	0.1698	0.8143	0.0265	0.1062	0.1310	0.8823
0.975	0.1134	0.4957	0.0437	0.0475	0.1135	2.7113	0.1641	0.8071	0.0186	0.0784	0.0969	0.8775
0.990	0.0729	0.3143	0.0431	0.0446	0.1085	2.7499	0.1606	0.8029	0.0117	0.0509	0.0630	0.8744
1.000	0.0000	0.0000	0.0400	0.0427	0.1051	2.7756	*******	0.8000	0.0000	0.0001	0.0001	1.0000

R/RO	100*GS	P(I)DIA	LAMBDA(I)	BETA(I)	TAN(BI)	BETA	TAN(B)	SIG-OP	SIG-T	SIG-L	SIG-I	MARGIN
0.300	0.0012	1.0445	0.3325	47.940	1.1083	38.789	0.8037	3.3118	0.5354	0.0003	0.5356	6.1831
0.350	1.3021	1.1009	0.3504	45.036	1.0013	35.918	0.7244	2.5621	0.3977	0.2020	0.5996	4.2723
0.400	1.7870	1.1505	0.3662	42.477	0.9156	33.585	0.6640	2.0338	0.3206	0.2182	0.5388	3.7745
0.450	2.1071	1.1934	0.3799	40.170	0.8442	31.636	0.6161	1.6512	0.2700	0.2128	0.4827	3.4208
0.500	2.3227	1.2296	0.3914	38.054	0.7828	29.971	0.5767	1.3668	0.2336	0.2005	0.4340	3.1490
0.550	2.4559	1.2594	0.4009	36.086	0.7288	28.521	0.5434	1.1502	0.2059	0.1860	0.3918	2.9352
0.600	2.5174	1.2828	0.4083	34.238	0.6806	27.236	0.5147	0.9817	0.1840	0.1711	0.3551	2.7644
0.650	2.5131	1.3004	0.4139	32.489	0.6368	26.081	0.4895	0.8492	0.1663	0.1567	0.3229	2.6261
0.700	2.4462	1.3124	0.4177	30.827	0.5968	25.031	0.4670	0.7406	0.1517	0.1432	0.2948	2.5119
0.750	2.3180	1.3192	0.4199	29.244	0.5599	24.065	0.4466	0.6526	0.1394	0.1308	0.2702	2.4150
0.800	2.1277	1.3214	0.4206	27.734	0.5258	23.168	0.4279	0.5797	0.1291	0.1197	0.2487	2.3300
0.850	1.8710	1.3196	0.4200	26.296	0.4941	22.328	0.4107	0.5185	0.1203	0.1100	0.2302	2.2518
0.900	1.5353	1.3143	0.4183	24.930	0.4648	21.536	0.3946	0.4668	0.1129	0.1016	0.2144	2.1762
0.925	1.3278	1.3106	0.4172	24.275	0.4510	21.156	0.3870	0.4438	0.1097	0.0978	0.2075	2.1383
0.950	1.0798	1.3063	0.4158	23.638	0.4377	20.784	0.3795	0.4225	0.1067	0.0944	0.2011	2.1001
0.975	0.7585	1.3015	0.4143	23.020	0.4249	20.421	0.3723	0.4027	0.1041	0.0912	0.1952	2.0619
0.990	0.4771	1.2984	0.4133	22.659	0.4175	20.208	0.3681	0.3914	0.1026	0.0893	0.1918	2.0403
1.000	0.0010	1.2963	0.4126	22.422	0.4126	20.066	0.3653	0.3842	0.0952	*******	*******	0.0000

GAWN-BURRILL COEFFICIENTS AT 0.700 RADIUS TAU(C) = 0.2048 SIGMA = 0.6233

HYDRONAUTICS INC. *** PROPELLER DESIGN PROGRAM 192 *** PROPELLER NUMBER 7604-110
(ARBITRARY CIRCULATION LIFTING LINE *** VERSION 7, FEL,1975)

1.4000 J	CT = 0.2567	CTI = 0.2661	MAX CHORD AT 0.590R	0.0370 T/D AT 0.300R
0.4456 LAMBDA	CP = 0.2968	CPI = 0.2805	ROOT CHORD IS 0.590	0.0230 T/D AT 0.600R
0.3000 HUB RADIUS	KT = 0.1975	KTI = 0.2048	OF MAX CHORD	0.0100 T/D AT 0.900R
5.0000 BLADES	KQ = 0.0509	KQI = 0.0481	SIG-T = 2.3800 * T/C	0.0400 T/C MIN
0.5000 EAR	ETA= 0.8646	ETAI= 0.9486	SIG-L = 0.5560 * CL	0.0100 CD AT ROOT
				0.0080 CD AT TIP
				2.9600 ADVANCE SIGMA
				0.2567 CT REQUIRED
				1.0369 CTI/CT

R/RO	0.2999	0.3468	0.4749	0.6499	0.8249	0.9531	1.0000
CIRCG	0.0000	0.5400	0.9400	1.0400	0.8200	0.4300	0.0000
FAIRED	0.0000	0.5424	0.9377	1.0397	0.8227	0.4274	0.0000
AWAKE	0.3400	0.3010	0.2010	0.1100	0.0470	0.0190	0.0100
TWAKE	0.0210	0.0200	0.0160	0.0110	0.0070	0.0050	0.0020

R/RO	C/D	100*T/D	T/C	UT/2V	UA/2V	VT/V	CL	100*CD	CL*C/D	CT	CP	ETAB
0.300	0.1612	3.7000	0.2296	0.1021	0.0660	0.9085	0.0004	1.0000	0.0001	-0.0006	0.0004	-1.6026
0.350	0.2070	3.4465	0.1665	0.1053	0.0795	1.0245	0.2879	0.9857	0.0596	0.0246	0.0246	0.9325
0.400	0.2352	3.2018	0.1362	0.1061	0.0907	1.1385	0.3159	0.9714	0.0743	0.0403	0.0415	0.9400
0.450	0.2537	2.9655	0.1169	0.1047	0.0996	1.2512	0.3146	0.9571	0.0798	0.0548	0.0583	0.9410
0.500	0.2654	2.7370	0.1031	0.1015	0.1063	1.3627	0.3028	0.9429	0.0804	0.0681	0.0744	0.9395
0.550	0.2717	2.5155	0.0926	0.0969	0.1108	1.4734	0.2868	0.9286	0.0779	0.0798	0.0892	0.9368
0.600	0.2731	2.3000	0.0842	0.0913	0.1132	1.5834	0.2691	0.9143	0.0735	0.0896	0.1021	0.9330
0.650	0.2699	2.0893	0.0774	0.0848	0.1135	1.6928	0.2511	0.9000	0.0678	0.0969	0.1122	0.9284
0.700	0.2622	1.8816	0.0718	0.0778	0.1120	1.8017	0.2330	0.8857	0.0613	0.1016	0.1192	0.9232
0.750	0.2498	1.6744	0.0670	0.0704	0.1086	1.9102	0.2176	0.8714	0.0544	0.1033	0.1226	0.9173
0.800	0.2321	1.4638	0.0631	0.0628	0.1036	2.0184	0.2029	0.8571	0.0471	0.1017	0.1218	0.9110
0.850	0.2078	1.2433	0.0598	0.0552	0.0971	2.1263	0.1900	0.8429	0.0395	0.0962	0.1160	0.9045
0.900	0.1748	1.0000	0.0572	0.0477	0.0892	2.2339	0.1792	0.8286	0.0313	0.0854	0.1035	0.8980
0.925	0.1533	0.8615	0.0562	0.0441	0.0848	2.2877	0.1746	0.8214	0.0268	0.0771	0.0936	0.8950
0.950	0.1266	0.7011	0.0554	0.0404	0.0801	2.3414	0.1708	0.8143	0.0216	0.0656	0.0797	0.8921
0.975	0.0903	0.4957	0.0549	0.0369	0.0752	2.3950	0.1677	0.8071	0.0152	0.0484	0.0588	0.8895
0.990	0.0573	0.3143	0.0548	0.0348	0.0721	2.4272	0.1665	0.8029	0.0095	0.0314	0.0382	0.8884
1.000	0.0000	0.0000	0.0400	0.0334	0.0700	2.4486	*******	0.8000	0.0000	0.0001	0.0001	1.0000

R/RO	100*GS	P(I)DIA	LAMBDA(I)	BETA(I)	TAN(BI)	BETA	TAN(B)	SIG-OP	SIG-T	SIG-L	SIG-I	MARGIN
0.300	0.0009	1.2408	0.3950	52.781	1.3165	45.274	1.0096	3.5862	0.5464	0.0002	0.5466	6.5607
0.350	0.9855	1.3039	0.4151	49.860	1.1859	42.576	0.9188	2.8202	0.3963	0.1601	0.5563	5.0690
0.400	1.3414	1.3570	0.4319	47.199	1.0799	40.238	0.8462	2.2834	0.3240	0.1757	0.4997	4.5696
0.450	1.5703	1.4010	0.4460	44.742	0.9910	38.169	0.7860	1.8908	0.2782	0.1749	0.4530	4.1732
0.500	1.7199	1.4370	0.4574	42.454	0.9149	36.308	0.7348	1.5940	0.2454	0.1684	0.4137	3.8524
0.550	1.8082	1.4659	0.4666	40.311	0.8484	34.614	0.6902	1.3635	0.2204	0.1594	0.3798	3.5901
0.600	1.8444	1.4885	0.4738	38.296	0.7897	33.059	0.6509	1.1807	0.2005	0.1496	0.3500	3.3728
0.650	1.8334	1.5054	0.4792	36.397	0.7372	31.621	0.6157	1.0330	0.1842	0.1396	0.3238	3.1897
0.700	1.7782	1.5173	0.4830	34.604	0.6900	30.284	0.5840	0.9119	0.1708	0.1300	0.3007	3.0319
0.750	1.6800	1.5247	0.4853	32.908	0.6471	29.036	0.5551	0.8112	0.1595	0.1210	0.2805	2.8919
0.800	1.5385	1.5282	0.4864	31.302	0.6080	27.867	0.5287	0.7266	0.1501	0.1128	0.2629	2.7632
0.850	1.3507	1.5280	0.4864	29.778	0.5722	26.768	0.5044	0.6547	0.1424	0.1057	0.2480	2.6397
0.900	1.1073	1.5244	0.4852	28.331	0.5391	25.733	0.4820	0.5931	0.1362	0.0996	0.2358	2.5152
0.925	0.9575	1.5213	0.4843	27.633	0.5235	25.236	0.4715	0.5656	0.1337	0.0971	0.2308	2.4502
0.950	0.7787	1.5175	0.4830	26.952	0.5085	24.754	0.4611	0.5400	0.1318	0.0949	0.2267	2.3815
0.975	0.5472	1.5130	0.4816	26.287	0.4939	24.284	0.4512	0.5160	0.1306	0.0932	0.2238	2.3056
0.990	0.3443	1.5098	0.4806	25.894	0.4855	24.007	0.4454	0.5024	0.1305	0.0926	0.2231	2.2520
1.000	0.0007	1.5076	0.4799	25.636	0.4799	23.826	0.4416	0.4937	0.0952	*******	*******	0.0000

GAWN-BURRILL COEFFICIENTS AT 0.700 RADIUS TAU(C) = 0.1990 SIGMA = 0.8258

HYDRONAUTICS INC. *** PROPELLER DESIGN PROGRAM 192 *** PROPELLER NUMBER 7694-110-36
(ARBITRARY CIRCULATION LIFTING LINE *** VERSION 7, FEB.1975)

1.6000 J			CT = 0.3219		CTI = 0.3366		MAX CHORD AT 0.840R			0.0400 T/D AT 0.300R			
0.5092 LAMBDA			CP = 0.4063		CPI = 0.3849		ROOT CHORD IS 0.420			0.0210 T/D AT 0.600R			
0.3000 HUB RADIUS			KT = 0.3234		KTI = 0.3384		OF MAX CHORD			0.0120 T/D AT 0.900R			
5.0000 BLADES			KQ = 0.1040		KQI = 0.0985		SIG-T = 2.3800 * T/C			0.0300 T/C MIN			
0.7800 EAR			ETA= 0.7922		ETAI= 0.8745		SIG-L = 0.5560 * CL			0.0100 CD AT ROOT			
										0.0080 CD AT TIP			
R/RO	0.2999	0.3468	0.4749	0.6499	0.8249	0.9531	1.0000			0.9143 ADVANCE SIGMA			
CIRCG	0.0000	0.5000	0.8750	1.0150	0.8150	0.4700	0.0000			0.3219 CT REQUIRED			
FAIRED	0.0000	0.5014	0.8780	1.0029	0.8330	0.4564	0.0000			1.0459 CTI/CT			
AWAKE	0.3400	0.3010	0.2010	0.1100	0.0470	0.0190	0.0100						
IWAKE	0.0210	0.0200	0.0160	0.0110	0.0070	0.0050	0.0020						

R/RO	C/D	100*T/D	T/C	UT/V	UA/2V	VT/V	CL	100*CD	CL*C/D	CT	CP	ETAB
0.300	0.1878	4.0000	0.2130	0.1538	0.0795	0.8451	0.0005	1.0000	0.0001	-0.0006	0.0003	-2.8296
0.350	0.2193	3.5867	0.1636	0.1570	0.0954	0.9083	0.4189	0.9857	0.0919	0.0273	0.0309	0.9489
0.400	0.2502	3.2167	0.1285	0.1573	0.1089	1.0492	0.4611	0.9714	0.1154	0.0456	0.0525	0.9561
0.450	0.2805	2.8831	0.1028	0.1552	0.1202	1.1485	0.4457	0.9571	0.1250	0.0633	0.0740	0.9566
0.500	0.3098	2.5868	0.0835	0.1511	0.1292	1.2466	0.4103	0.9429	0.1271	0.0801	0.0952	0.9545
0.550	0.3381	2.3264	0.0688	0.1454	0.1361	1.3436	0.3684	0.9286	0.1245	0.0955	0.1152	0.9507
0.600	0.3648	2.1000	0.0576	0.1386	0.1410	1.4398	0.3259	0.9143	0.1189	0.1088	0.1332	0.9454
0.650	0.3897	1.9052	0.0489	0.1308	0.1439	1.5353	0.2853	0.9000	0.1112	0.1197	0.1485	0.9388
0.700	0.4119	1.7386	0.0422	0.1224	0.1449	1.6303	0.2478	0.8857	0.1021	0.1276	0.1603	0.9305
0.750	0.4304	1.5954	0.0371	0.1136	0.1442	1.7248	0.2137	0.8714	0.0920	0.1319	0.1679	0.9204
0.800	0.4432	1.4681	0.0331	0.1045	0.1418	1.8189	0.1830	0.8571	0.0811	0.1322	0.1704	0.9080
0.850	0.4468	1.3445	0.0301	0.0955	0.1379	1.9126	0.1550	0.8429	0.0693	0.1271	0.1664	0.8926
0.900	0.4334	1.3001	0.0300	0.0865	0.1327	2.0061	0.1292	0.8286	0.0560	0.1147	0.1530	0.8728
0.925	0.4146	1.2437	0.0300	0.0820	0.1296	2.0527	0.1165	0.8214	0.0483	0.1043	0.1408	0.8601
0.950	0.3801	1.1402	0.0300	0.0776	0.1262	2.0993	0.1036	0.8143	0.0394	0.0893	0.1224	0.8443
0.975	0.3115	0.9345	0.0300	0.0732	0.1225	2.1458	0.0894	0.8071	0.0278	0.0661	0.0928	0.8224
0.990	0.2240	0.6720	0.0300	0.0706	0.1202	2.1736	0.0787	0.8029	0.0176	0.0429	0.0616	0.8015
1.000	0.0000	0.0000	0.0300	0.0688	0.1186	2.1922	*******	0.8000	0.0000	0.0001	0.0001	1.0000

R/RO	100*GS	P(I)DIA	LAMBDA(I)	BETA(I)	TAN(BI)	BETA	TAN(B)	SIG-OP	SIG-T	SIG-L	SIG-I	MARGIN
0.300	0.0013	1.6784	0.5343	60.684	1.7808	49.219	1.1593	1.2802	0.5070	0.0003	0.5072	2.5238
0.350	1.4050	1.7215	0.5480	57.433	1.5656	46.503	1.0539	1.0168	0.3895	0.2329	0.6223	1.6338
0.400	1.9205	1.7584	0.5597	54.449	1.3993	44.126	0.9699	0.8306	0.3059	0.2564	0.5623	1.4770
0.450	2.2599	1.7896	0.5696	51.693	1.2659	42.002	0.9005	0.6931	0.2446	0.2478	0.4924	1.4074
0.500	2.4909	1.8153	0.5778	49.130	1.1557	40.077	0.8419	0.5884	0.1987	0.2281	0.4268	1.3785
0.550	2.6386	1.8359	0.5844	46.737	1.0625	38.312	0.7901	0.5065	0.1638	0.2048	0.3686	1.3740
0.600	2.7150	1.8517	0.5894	44.491	0.9824	36.680	0.7448	0.4411	0.1370	0.1812	0.3181	1.3862
0.650	2.7263	1.8631	0.5930	42.376	0.9124	35.163	0.7044	0.3879	0.1164	0.1586	0.2749	1.4106
0.700	2.6751	1.8702	0.5953	40.379	0.8504	33.744	0.6680	0.3440	0.1004	0.1378	0.2382	1.4440
0.750	2.5612	1.8735	0.5964	38.489	0.7951	32.413	0.6349	0.3073	0.0882	0.1188	0.2070	1.4844
0.800	2.3815	1.8731	0.5962	36.697	0.7453	31.159	0.6047	0.2764	0.0788	0.1017	0.1805	1.5306
0.850	2.1275	1.8694	0.5950	34.994	0.7000	29.976	0.5768	0.2499	0.0716	0.0862	0.1578	1.5838
0.900	1.7792	1.8625	0.5929	33.374	0.6587	28.856	0.5510	0.2272	0.0714	0.0718	0.1432	1.5865
0.925	1.5556	1.8580	0.5914	32.593	0.6394	28.318	0.5389	0.2170	0.0714	0.0648	0.1361	1.5934
0.950	1.2802	1.8528	0.5898	31.832	0.6208	27.794	0.5271	0.2075	0.0714	0.0576	0.1290	1.6083
0.975	0.9111	1.8469	0.5879	31.088	0.6029	27.282	0.5157	0.1986	0.0714	0.0497	0.1210	1.6399
0.990	0.5780	1.8430	0.5867	30.650	0.5926	26.981	0.5091	0.1935	0.0714	0.0438	0.1151	1.6806
1.000	0.0012	1.8403	0.5858	30.362	0.5858	26.783	0.5048	0.1903	0.0714	*******	*******	0.0000

GAWN-BURRILL COEFFICIENTS AT 0.700 RADIUS TAU(C) = 0.2187 SIGMA = 0.3095

Lifting Line Program Output

The lifting line calculations were carried out using the HYDRONAUTICS, Incorporated computer program PR 192, Version 7. Besides the Lerbs theory, this program also carries out calculations for the basic blade geometry and provides information on cavitation inception. An explanation of the contents and notations on the output page is presented below.

The propeller number is listed in the title block along with the program number, which version of the program, and the date of the last revision. This write-up applies to Version 7, revised February 1975.

Input parameters are listed at the top of the output page. The first column of five items contains:

J: The advance ratio = V/nD where V is the ship velocity ($V = V_s$), n is rotative speed in rps and D is the diameter.

LAMBDA: LAMBDA = J/π = $V/\pi nD$. LAMBDA is the ratio of tip speed to ship speed or tan (β) at the tip, where β is the inflow angle based on ship speed.

HUB RADIUS: This is the hub radius expressed as a fraction of the total radius

BLADES: The number of blades on the propeller

EAR: The expanded blade area ratio for all the blades on the propeller

The second column of five items:

CT: Thrust loading coefficient $= \dfrac{T}{\frac{1}{2}\rho V^2 \left(\frac{\pi}{4} D^2\right)}$

$CT = KT\,(8/(\pi J^2))$ where T is the thrust in lbs.

CP: Power loading coefficient $= \dfrac{P}{\frac{1}{2}\rho V^2 \left(\frac{\pi}{4} D^2\right) V \cdot D}$

$CP = KW\,(16/J^3)$ where P is the input power in foot pounds per second

KT: Thrust coefficient $= \dfrac{T}{\rho n^2 D^4} = KT = CT(\pi J^2/8)$

KQ: Torque coefficient $= \dfrac{Q}{\rho n^2 D^5} = KQ = CP(J^3/16)$

ETA: ETA (η) is the overall propeller efficiency

$ETA = \dfrac{CT}{CP} = \dfrac{KT}{KW}\dfrac{J}{2\pi}$. This is the efficiency of the blades only and does not include hub losses due to cavitation.

This efficiency (η) is related to open water efficient (η_o) by $\eta = \eta_o \eta_{rr}/(1-w)$, where w = mean volumetric wake. P.C., therefore, equals $\eta(1-t)$.

The third column of five items corresponds to the previous column except that they refer to the "ideal" values. That is, the values associated with the potential flow, escluding losses from skin friction. (ETAI) therefore represents the "ideal" efficiency and is a measure of induced losses. The difference between (ETA) and (ETAI) is a measure of losses due to blade friction drag.

The fourth column presents the radial location of the maximum blade chord as a fraction of the propeller radius, and the radio of blade root chord to maximum chord. The last two items in this column are the equations for obtaining the incipient cavitation number due to thickness (SIG-T) and loading (SIG-L). The constants in these equations are read as input data.

The last column of 9 lines contains the input thickness diameter ratios and the radii at which they occur along with the minimum thickness chord ratio. These are used to provide a curve fit to the required thickness distribution. The next two items are the input drag coefficients at the blade root and tip. A linear interpolation between these values is used to obtain the drag coefficients at all other radii. The (ADVANCE SIGMA) is the reference cavitation number based on the ship velocity, (CT REQUIRED) is the specified thrust coefficient. An iteration procedure is required in the program to develop the required thrust. Therefore (CT REQUIRED) should be compared with the final (CT), Column 2, to assure that the final thrust is adequately close to the required thrust. The ratio (CTI/CT) is a measure of the additional ideal thrust the propeller must produce to overcome its own frictional losses.

The first row labeled (R/RO) is the nondimensional radii at which the form of the circulation distribution has been specified. The row labeled (CIRCG) is the input values of circulation distribution at the corresponding radii. If faired data has been required, a third row containing the faired circulation distribution is printed and labeled (FAIRED). If unfaired output is

requested this row is omitted. The two following rows of input, labeled (AWAKE) and (TWAKE), are, respectively, the mean values of nondimensional radii.

The following two sets of data are the computed output. These data have been rounded off, not truncated, to the number of decimal places provided.

R/RO: Nondimensional radii specified for output on the first input data card. Each item in a given row pertains to the radii R/RO listed at the left of the page.

C/D: Blade chord-diameter ratio.

100*T/D: One hundred times the thickness diameter ratio.

T/C: Thickness chord ratio.

UT/2V: Tangential induced velocity at lifting line nondimensionalized with respect to ship velocity.

UA/2V: Axial induced velocity at lifting line nondimensionalized with respect to ship velocity.

VT/V: Ratio of total velocity at blade (including induced velocities) to ship velocity.

CL: Section lift coefficient based on VT. Note that CL is undefined at the blade tip where both lift and chord go to zero.

100*CD: One hundred times the section drag coefficient based on VT.

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CL*C/D: Radial load parameter. This is like a lift coefficient but is based on diameter instead of blade chord. It is therefore independent of the blade planform.

CT: Differential thrust coefficient per blade. This value, integrated over the length of the blade and multiplied by the number of blades will yield the total CT listed in column two at the top of the page.

CP: Differential power coefficient per blade. This value, integrated over the length of the blade and multiplied by the number of blades will yield the total CP listed in column two at the top of the page.

ETAB: Blading efficiency (η_{BLADE}). This is the ratio of useful work done on the fluid to the total work input. It is useful in selecting the blade planform.

$$\eta_{BLADE} = \frac{1 - (CD/CL)\tan(\beta_1)}{1 + (CD/CL)/\tan(\beta_1)}$$

η_{BLADE} is undefined at the blade tip. The tip value can be obtained by extrapolating the other values to the tip. η_{BLADE} is usually negative at the root since the root section usually has a net drag (CT is negative at the root).

100*GS: One hundred times the nondimensional circulation. GS = Circulation/πDV

P(I)DIA: Hydrodynamic (including induced flow) pitch-diameter ratio (hydrodynamic advance ratio).

LAMBDA(I): Hydrodynamic (including induced flow) pitch-circumference ratio.
λ_i = (Pitch-diameter ratio)/π = (R/RO)tan(β_i).

BETA(I): Hydrodynamic advance angle in degrees, β_i. (Including induced flow).

TAN(BI): Tangent of hydrodynamic advance angle, tan (β_i). This is the ratio of tangential velocity to axial velocity at each blade section.
tan (β_i) = λ_i/(R/RO).

BETA: Geometric pitch angle in degrees, β.

TAN(B): Tangent of geometric pitch angle
tan (B) = λ/R/RO).

SIG-OP: Operating cavitation number (σ_{OP}) at each radius based on ADVANCE SIGMA and VT.

SIG-T: Incipient cavitation number due to thickness, $\sigma_{i(thickness)}$.

SIG-L: Incipient cavitation number due to loading, $\sigma_{i(loading)}$.

SIG-I: Total section incipient cavitation number, σ_i.
$\sigma_i = \sigma_{i(thickness)} + \sigma_{i(loading)}$.

MARGIN: This is the ratio of σ_{OP} to σ_i and represents the V^2 margin each section has over cavitation inception.

The last line of output has the Gawn-Burrill coefficients computed at the 0.7 radius.

TACU(C): The "mean" lift coefficient

$$\tau_c = \frac{T}{\frac{1}{2}\rho V_R A_P}$$

SIGMA: Local cavitation number

$$\sigma_R = (P_o - P_v)/\tfrac{1}{2}\rho V_R^2$$

where

$$V_R = V\sqrt{1 + (0.7\pi/J)^2}$$

V = Ship velocity

A_P: Approximate projected blade area

A_P = EAR $(1.067-0.229\ P/D)D^2\ (\pi/4)$

P_o = Static pressure

P_v = Vapor pressure